Department of Mines.

NEW ZEALAND GEOLOGICAL SURVEY.

(J. M. BELL, Director.)

BULLETIN No. 7 (NEW SERIES).

THE GEOLOGY

OF THE

QUEENSTOWN SUBDIVISION,

WESTERN OTAGO DIVISION.

BY

JAMES PARK, F.G.S.,

Professor of Applied Geology in the University of Otago, and Director of the Otago School of Mines.

ISSUED UNDER THE AUTHORITY OF THE HON. R. McKENZIE, MINISTER OF MINES.

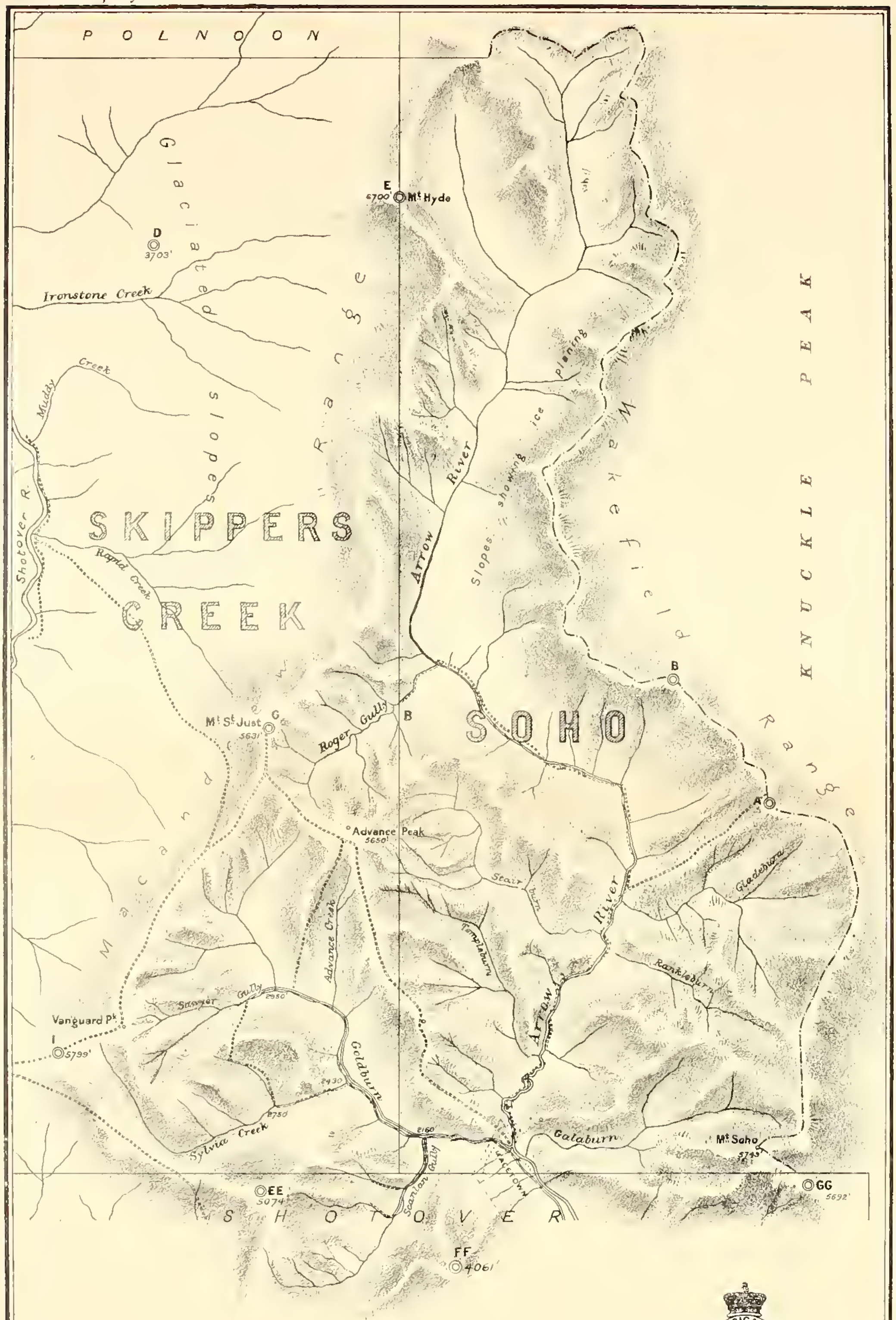
NEW ZEALAND.

BY AUTHORITY: JOHN MACKAY, GOVERNMENT PRINTER, WELLINGTON.

1909.

Photo P. Mahlghan.]

Queenstown, with the Remarkables in the background.



TOPOGRAPHY OF THE

ARROW WATERSHED

ABOVE MACETOWN

Scale of Chains

80 40 0 80 160

JAMES MACKINTOSH BELL
DIRECTOR

REFERENCE

Dray Roads ....
Bridle Paths ....

Field work by E.F. Roberts
under direction of James Park.

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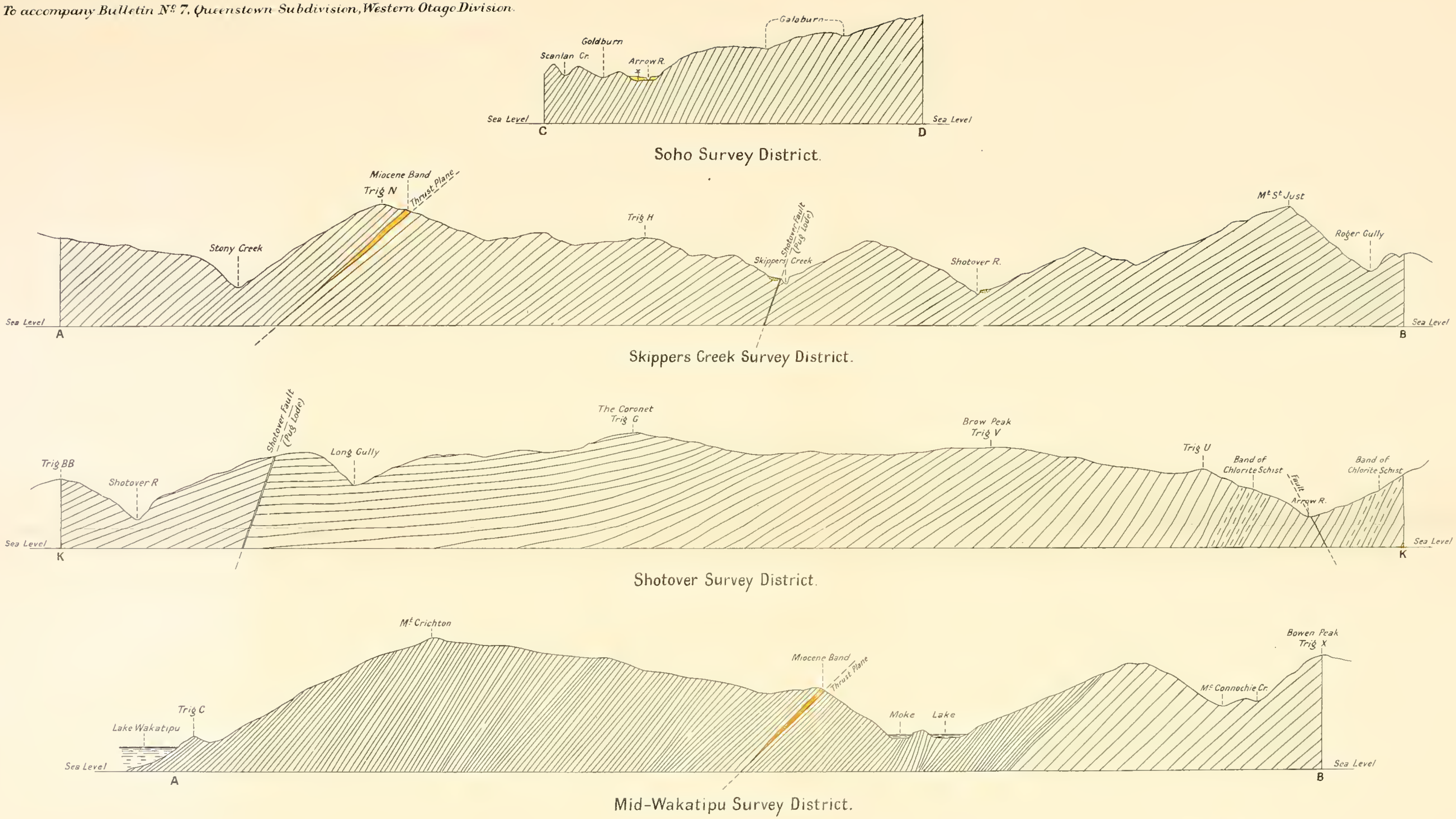

SECTIONS IN QUEENSTOWN SUBDIVISION

Scale of Chains

80 40 0 80 160

1 : 63360

Reference to Geological colours

PLEISTOCENE		MIOCENE	PALEOZOIC	
Newer	Older	Bob Cove Marine Beds.	Kakanui Series	Manuototo Series
Low Terrace Gravels.	*High Terrace Gravels*	*Sandstone, Limestone &c.*	*Upper Schists*	*Lower Schists*

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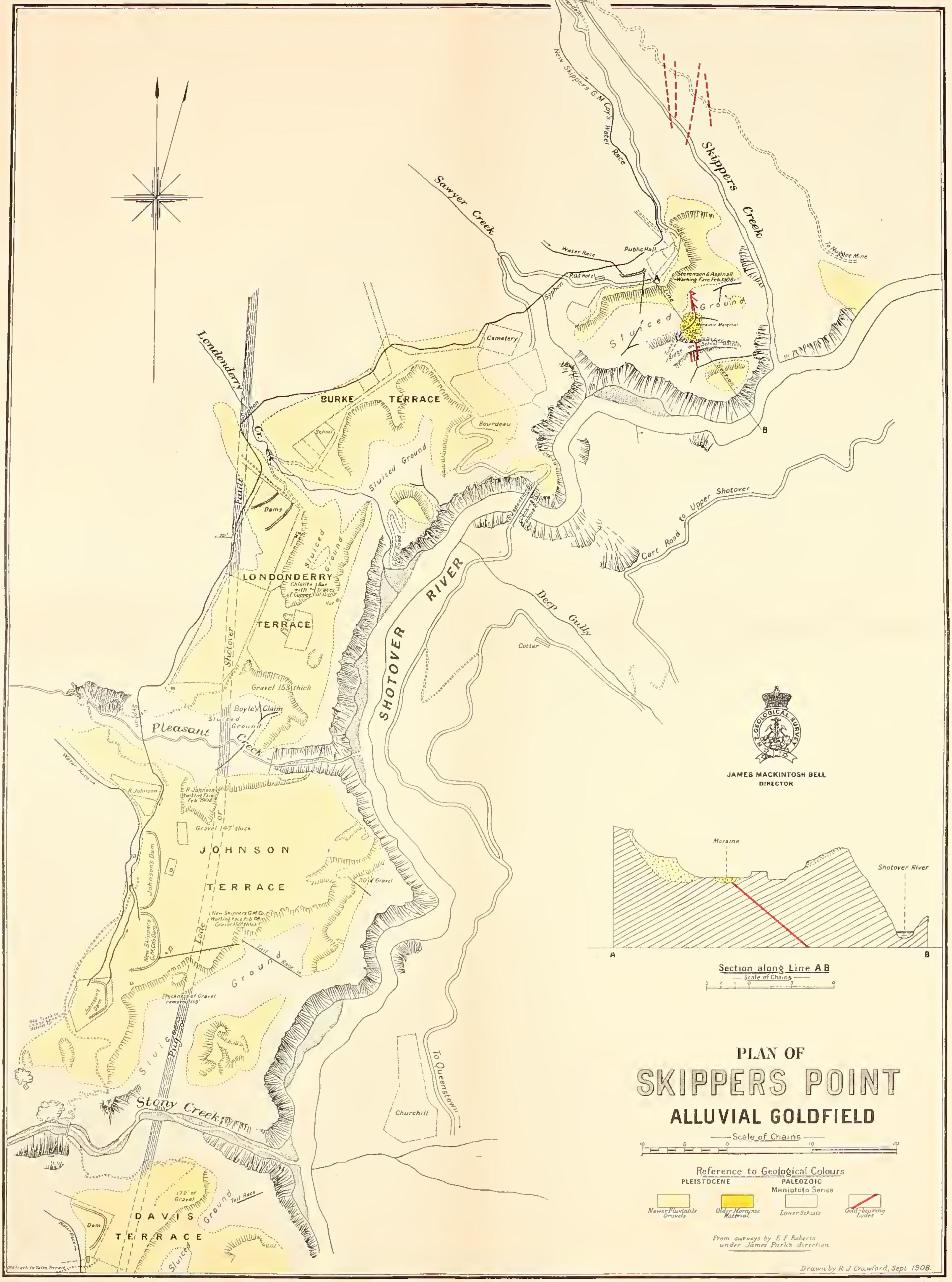

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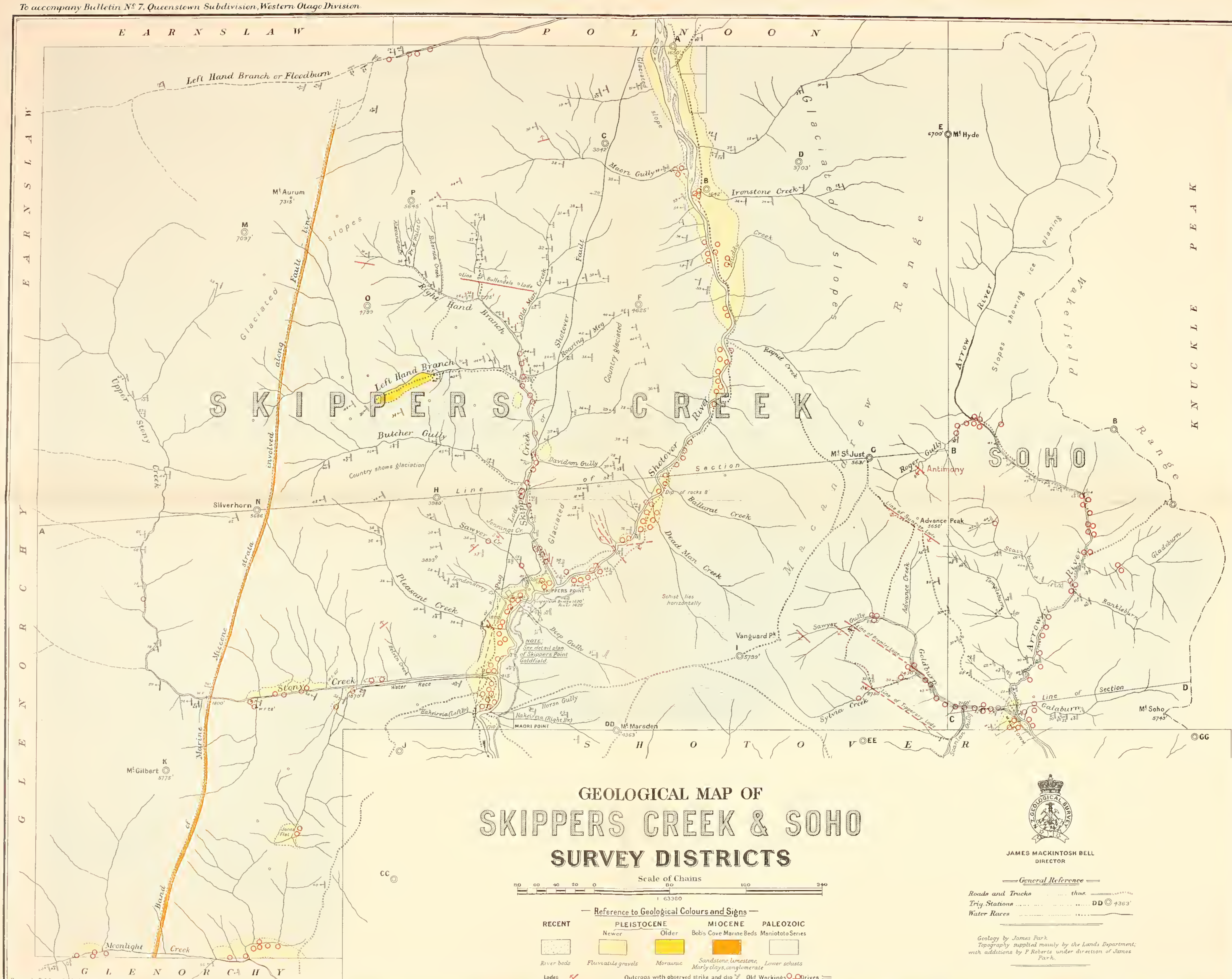
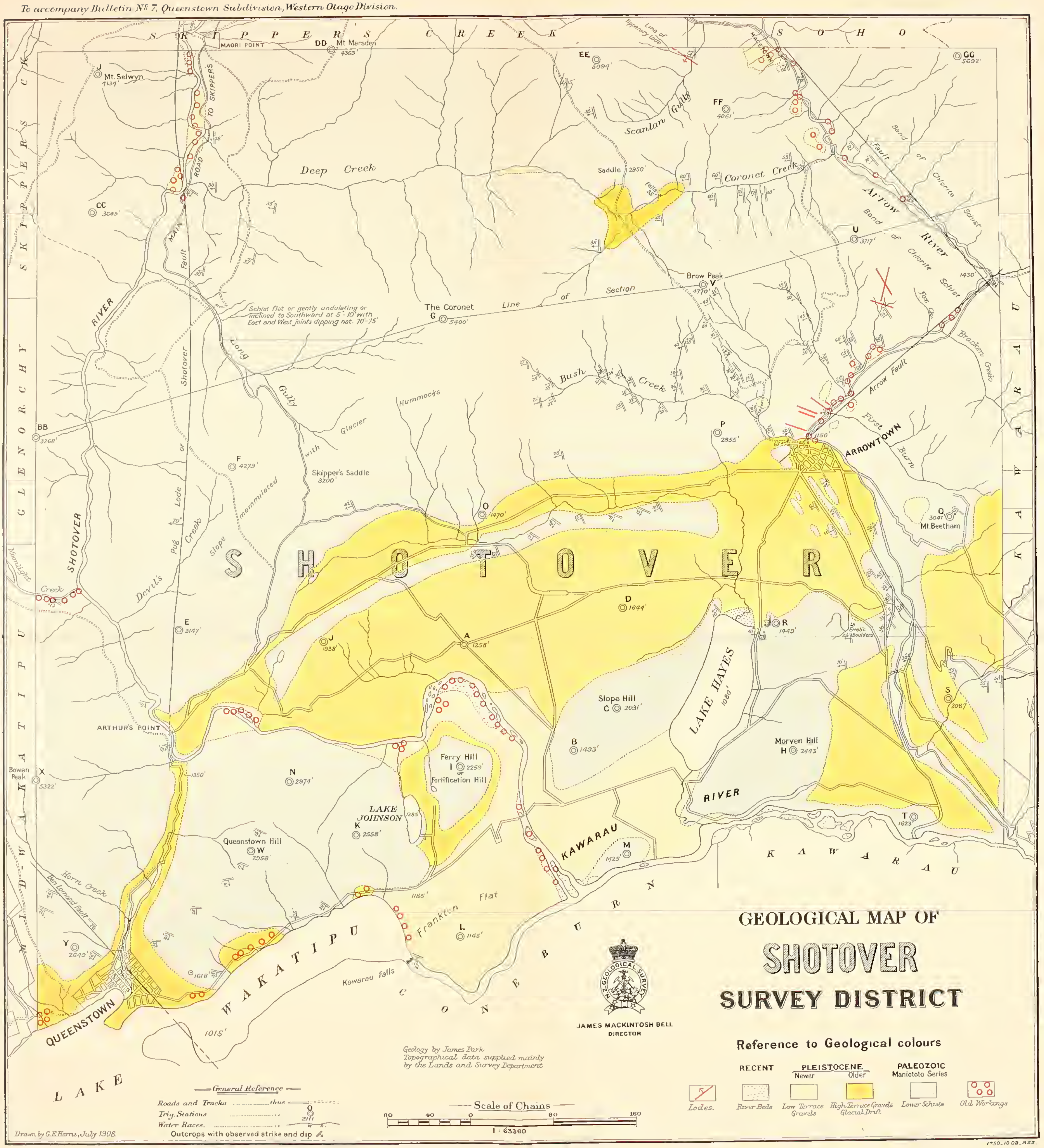
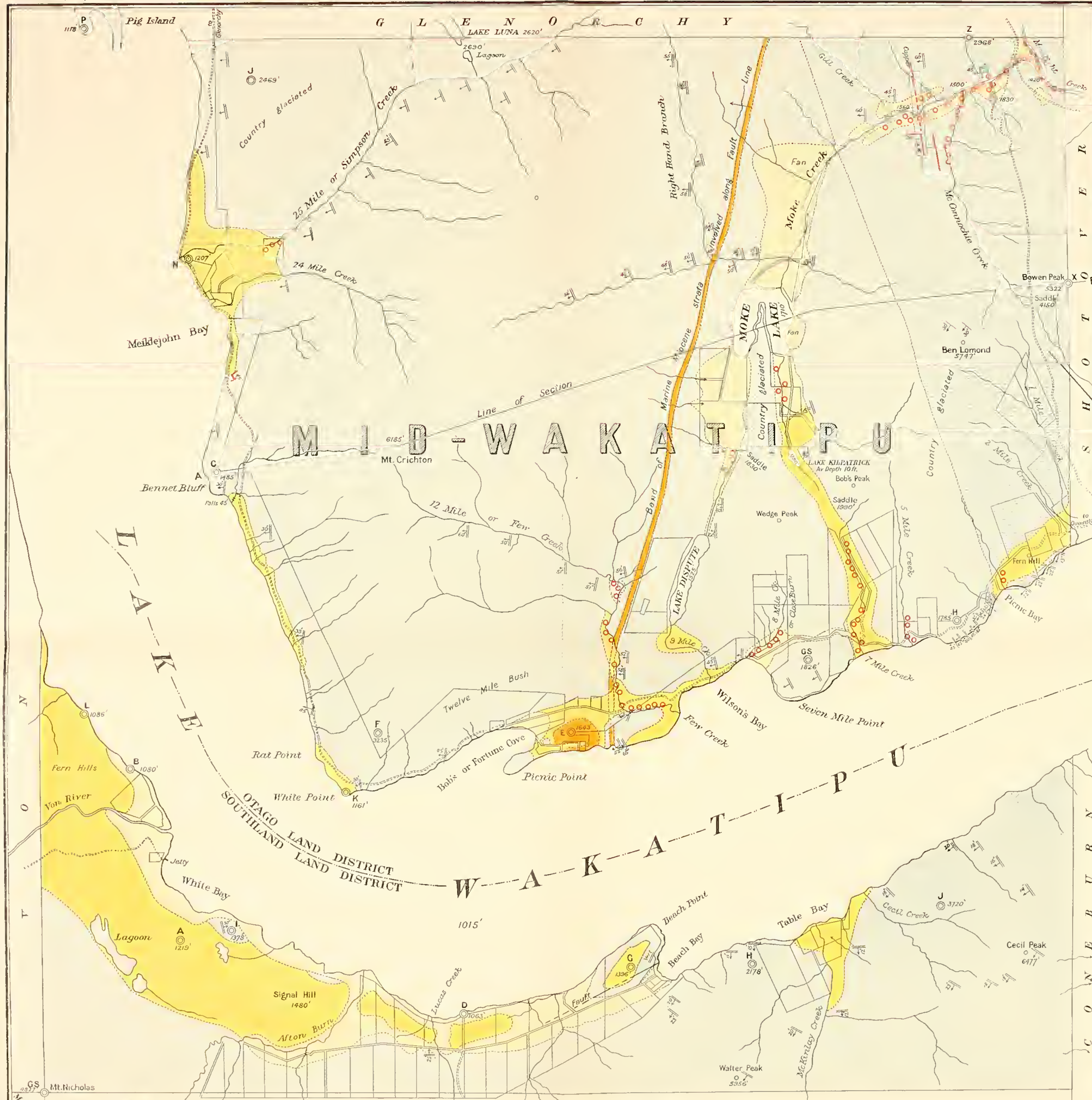

GEOLOGICAL MAP OF
SKIPPERS CREEK & SOHO
SURVEY DISTRICTS
N.Z. GEOLOGICAL SURVEY
JAMES MACKINTOSH BELL
DIRECTOR
Scale of Chains
80 60 40 20 0 80 160 240
1 63360
Reference to Geological Colours and Signs
RECENT
PLEISTOCENE
Newer
Older
MIOCENE
Bob's Cove Marine Beds
PALEOZOIC
Maniototo Series
River beds
Fluviatile gravels
Morainic
Sandstone, limestone, Marly clays, conglomerate
Lower schists
Lodes
Outcrops with observed strike and dip
Old Workings
Drives
General Reference
Roads and Tracks thus.
Trig. Stations DD 4363'
Water Races
Geology by James Park
Topography supplied mainly by the Lands Department; with additions by F Roberts under direction of James Park.
Drawn by R.J. Crawford, August 1908
SKIPPERS CREEK
SOHO
EARNSLAW
POLNOON
GLENORCHY
KNUCKLE PEAK
SHOTOVER
Left Hand Branch or Floodburn
Right Hand Branch
Left Hand Branch
Shotover River
Skippers Creek
Arrow River
Mt. Aurum
Silverhorn
Mt. St. Just
Mt. Hyde
Advance Peak
Vanguard Pk.
Mt. Gilbert
Mt. Marsden
Mt. Soho
Skippers Point
Maori Point
Moonlight Creek
Stony Creek
Upper Stony Creek
Butcher Gully
Pleasant Creek
Deep Gully
Dead Man Creek
Ballarat Creek
Macandrew Range
Wakefield Range
Glaciated slopes
Marine Miocene strata involved along Fault-line
Fault
Line of Section
Antimony
Schist lies horizontally
NOTE: See detail plan of Skippers Point Goldfield.

To accompany Bulletin No. 7, Queenstown Subdivision, Western Otago Division.



By Authority. John Mackay, Government Printer.
1450.10.08.822.

To accompany Bulletin No. 7, Queenstown Subdivision, Western Otago Division.



GEOLOGICAL MAP OF
MID-WAKATIPU SURVEY DISTRICT

Geology by James Park.
Topographical data mainly supplied by the Lands and Survey Department, with additions by H. Hamilton under James Park's direction.

JAMES MACKINTOSH BELL
DIRECTOR

Reference to Geological colours

RECENT	PLEISTOCENE Newer	PLEISTOCENE Older	MIOCENE Bob's Cove Marine Beds	PALEOZOIC Kakanui Series	PALEOZOIC Maniototo Series	
Lodes						
River Beds	Low Terrace Gravels	High Terrace Gravels	Sandstone, limestone, Marly clays, & conglomerate	Upper Schists	Lower Schists	Old Workings

General Reference
Roads and Tracks
Trig. Stations
Outcrops with observed strike and dip

Scale of Chains
80 40 0 80 160
1 : 63360

Drawn by G. E. Harris, July 1908

By Authority: John Mackay, Government Printer.
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LETTER OF TRANSMITTAL.

Geological Survey Office,

Wellington, 10th February, 1909.

Sir,—

I have the honour to submit herewith Bulletin No. 7 (new series) of the Geological Survey Department.

The bulletin covers a report on the geology of the Queenstown Subdivision, Western Otago, by Professor James Park, who was employed temporarily for five months during the field season of 1907–8.

It contains 112 pages of letterpress. It is illustrated by thirty-eight plates and by thirty-three figures scattered throughout the text. There are also thirteen maps and plans and one sheet of geological cross-sections.

I have the honour to be,

Sir,

Your obedient servant,

J. M. BELL,

Director, Geological Survey.

Hon. R. McKenzie,

Minister of Mines,

Wellington.

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MAPS AND PLANS.

GEOLOGICAL SECTIONS.

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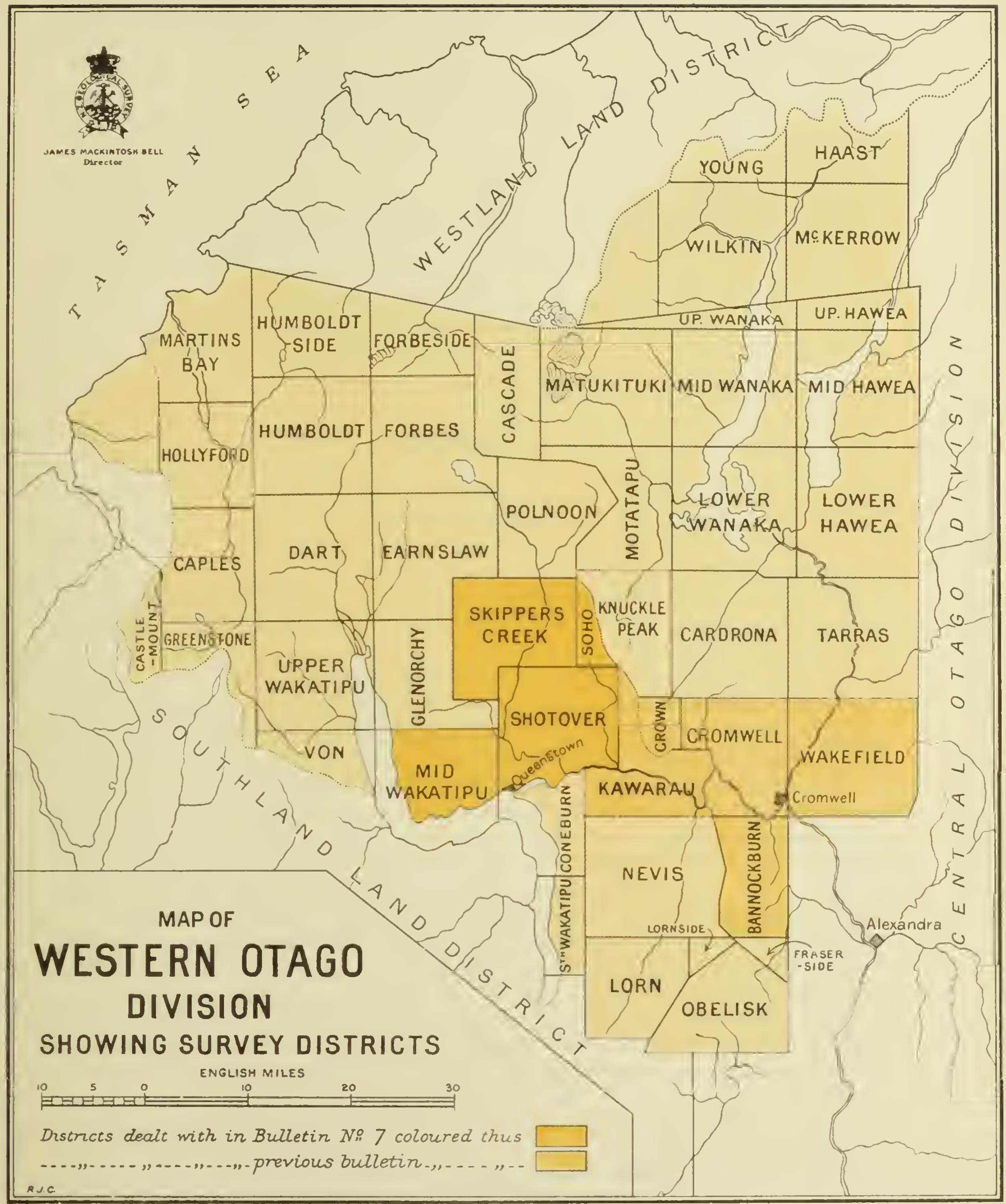
JAMES MACKINTOSH BELL
Director
TASMAN SEA
WESTLAND LAND DISTRICT
SOUTHLAND LAND DISTRICT
CENTRAL OTAGO DIVISION
YOUNG
HAAST
WILKIN
McKERROW
UP. WANAKA
UP. HAWEA
MARTINS BAY
HUMBOLDT SIDE
FORBESIDE
CASCADE
MATUKITUKI
MID WANAKA
MID HAWEA
HOLLYFORD
HUMBOLDT
FORBES
POLNOON
MOTATAPU
LOWER WANAKA
LOWER HAWEA
CAPLES
DART
EARNSLAW
SKIPPERS CREEK
SOHO
KNUCKLE PEAK
CARDRONA
TARRAS
CASTLE-MOUNT
GREENSTONE
UPPER WAKATIPU
GLENORCHY
SHOTOVER
CROWN
CROMWELL
WAKEFIELD
VON
MID WAKATIPU
Queenstown
KAWARAU
Cromwell
CONEBURN
NEVIS
BANNOCKBURN
STH WAKATIPU
LORNSIDE
FRASER-SIDE
Alexandra
LORN
OBELISK
MAP OF
WESTERN OTAGO DIVISION
SHOWING SURVEY DISTRICTS
ENGLISH MILES
10 5 0 10 20 30
Districts dealt with in Bulletin No. 7 coloured thus
- - - „ - - - - „ - - - „ - - - „ - previous bulletin - „ - - - - „ - -
R.J.C.

125' 08.1074

BULLETIN No. 7 (NEW SERIES).

THE GEOLOGY

OF THE

QUEENSTOWN SUBDIVISION.

WESTERN OTAGO DIVISION.

CHAPTER I.

INTRODUCTION.

General Description of District.

The area forming the theme of this report embraces within its limits the high mountainous region drained by the Shotover and its large tributaries—Skipper's, Moonlight, and Moke creeks—and by the Arrow River and its tributary the Goldburn. It extends from Macetown and the upper Arrow across the mountains to the Shotover Valley, whence it stretches westward to the sources of Skipper's Creek near Mount Aurum, and southward to Lake Wakatipu. From Queenstown it follows the shores of Lake Wakatipu to the Twenty-five-mile Creek, and reaches across the lake to the Eyre Mountains. Included within its boundaries are the survey districts of Mid-Wakatipu, Shotover, Skipper's Creek, and Soho.

Queenstown, with some seven or eight hundred inhabitants, is the county town and chief centre of population in the district. It is picturesquely situated on the raised lake-beaches and great moraine overlooking Queenstown Bay and Frankton Arm. Its scenic marvels and sunny salubrious climate have made it the chief centre of the tourist traffic in the South Island. It is easily accessible from Dunedin by train and steamer, a day's journey; from Invercargill by train and steamer, a day's journey; from Dunedin by the Otago Central route, by train to Clyde and thence by coach, a two-days' journey; or from Dunedin, *via* Clyde, Cromwell, and Lake Wanaka, a three-days' journey.

To those in search of health Queenstown is bright and invigorating, while to the enterprising holiday-seeker it affords plenty of scope for the display of activity in boating, walking, or mountaineering. The carpet of gentian, snowberry, and other native plants makes the slopes of Ben Lomond and Queenstown Hill especially beautiful and attractive in the months of January, February, and March. The autumnal tints of the foliage of the deciduous trees around Queenstown can only be described as marvellous and inimitable, being unapproached by anything the writer has seen in Great Britain or in any other part of the Dominion. The stately poplars in particular, with their glorious tints of pure chrome, stand up like shafts of gold against the sombre green of the native vegetation. They are a feast to the eye, and alone are worth a journey to the cold-lake region. Needless to say the mountains are seen at their best in winter—that is, from June to September—when covered with their mantle of snow. The following graphic description of this pleasant place is culled from the pages of a small pamphlet issued by the New Zealand Tourist Department :—

" Queenstown, besides being the centre from which many very fine scenic routes radiate, is a charming little retreat for a quiet holiday. It is one of the healthiest places in the colony, and its altitude (about 1,020 ft. above sea-level) and pure, dry, invigorating mountain air are important factors in its advantages as a natural sanatorium. As a winter resort for invalids suffering from affections of the lungs, Queenstown has the recommendation of many physicians. In the winter season the rainfall is small ; snow rarely lies for more than one or two days ; the atmosphere is calm, the nights frosty, and the days clear, bright, and warm. The summer climate has been likened to that of Northern Italy. Grapes, peaches, and other fruit requiring summer heat readily ripen in the open air.

" Unlike many New Zealand townships, Queenstown has a restful old-fashioned air, and its winding roads afford some charming walks. The Esplanade, curving round the white beach, is shaded by weeping-willows, and on the seats beneath the trees the visitor may leisurely enjoy the long summer evenings, or on his " lazy days " admire the changing tints on lake and crag, and watch the trout in the beautifully clear water, through which they may be seen as through a glass, outlined against the silver sands.

" The Queenstown Park, planted with tall eucalypti and pines, and English and native trees, adjoins the town on the south, where the olden Maori village Te Kirikiri once stood. It is a long, green peninsula, its slopes strewn with ancient moraine rocks, now fast being covered with climbing trailers. Queenstown Bay, viewed from here, is an enchanting picture, with the white village and the green woods and mountains all reflected perfectly in its surface. Along the waterside may be seen specimens of the flowering kowhai, covered in the early spring with golden blossoms. In the middle of the park, on the summit of the peninsula, is an ornamental lakelet, which in winter time is sometimes frozen hard enough for skating. A bowling-green has been laid down for the use of visitors. Many a pleasant hour may be spent in the park, and none more full of quiet enjoyment than in the calm evening-time, with the Remarkables and Mount Cecil and the turreted Walter Peaks full in view, bathed with exquisite sunset colours.

" Just at the back of the town is Queenstown Hill (2,958 ft.). There is a comfortably graded path to the summit, from which there are magnificent views of the lake, the Remarkables, the Crown Ranges, the green valley of the Kawarau, and the gorge of the Clutha. The climb, at an easy pace, occupies about three-quarters of an hour.

" Another favourite walk is to the Waterworks (time, twenty minutes each way), in a picturesque wooded valley about a mile from the town. The Ben Lomond Track above the Esplanade is followed until finger-posts show where the path diverges.

" Westward of the town a good road along the margin of the lake for several miles affords a charming walk or drive (half a day) as far as the ' Five-mile ' Creek. If a whole day is to be spent, Moke Lake may be visited on foot from the road. The distance to the ' Five-mile ' is in reality considerably less than five miles, but the creek was named, like the ' One-mile ' and ' Two-mile,' by the gold-diggers who had to fight their way through thick scrub and bracken around the trackless shores."

The Frankton or Kawarau Flat extends from the head of Frankton Arm to the mouth of the Shotover without a break, and beyond the Shotover reaches to the end of Lake Hayes. Between the Shotover and Arrow there lie the Arrow Downs, mostly in a state of high culti-

Queenstown Hill, from the Domain.

 [*To face p. 2.*

vation. The Crown Terrace is a wide rock-shelf some 700 ft. or 800 ft. above the level of the Arrow. It lies between the Arrow and the foot of the Crown Range, and is occupied by many prosperous farms.

There are no wide valleys bounded by undulating foothills, as are to be seen at Cromwell and Bannockburn. The Shotover and Arrow rivers, with their numerous tributaries, traverse narrow rocky gorges bounded by high mountains that possess in most places excessively steep slopes.

With the exception of the Crown Terrace, the Arrow Downs, and Frankton Flat, altogether less than fifty square miles in extent, and the narrow gorge-like valleys mentioned above, the area under review is occupied by a sea of high mountain-ranges and narrow ridges. Thus, north of the Arrow are the Crown Range, culminating in the Crown Peak, 5,673 ft. above sea-level ; the Motutapu Range, with Mount Soho, 5,743 ft., forming the divide between the Arrow and Motutapu ; the Macandrew Mountains, with Mount Hyde, 6,790 ft., Mount St. Just, 5,631 ft., Advance Peak, 5,700 ft., and Vangnard Peak, 5,799 ft., lying between the Arrow and Shotover ; and the Richardson Mountains, with Mount Aurum, 7,315 ft., Mount Larkins, 7,432 ft., Mount Hamlet, 7,200 ft., Mount Gilbert, 5,755 ft., Mount Crichton, 6,185 ft., and Ben Lomond, 5,747 ft., forming the divide between the Shotover and Lake Wakatipu ; and the Eyre Mountains on the south side of the lake, culminating in Walter Peak, 5,916 ft., and Cecil Peak, 6,477 ft.

Scope of the Work.

The work undertaken during the summer of 1907–8 included an investigation of the configuration and physical features of the land, special attention being paid to the evidences of former glaciation ; of the rock-formations and general geological structure ; of the nature and extent of the gold-bearing alluvial drifts ; of the gold-bearing lodes at Macetown, Skipper's, and Arrow ; and of water-supply. In connection with the latter, gaugings were taken of the Arrow and Shotover rivers and their numerous tributaries. The Kawarau River was also gauged by the measurement of three cross-sections at points about half a mile below the Falls, and by systematic velocity-determinations. At the same time a graduated gauge was fixed in the river in terms of a carefully determined datum, and arrangements made for daily readings to be recorded from now onward for all time.

During the progress of the work a bathymetrical survey was made of Lake Hayes, Moke Lake, Lake Johnson, and Lake Kilpatrick ; and numerous barometric altitudes were recorded, and in most cases checked by subsequent readings, in order to obtain results with a reasonable degree of accuracy.

The courses of the rivers and streams, and the positions of such fixed points as trigonometrical stations, shown on the accompanying maps, were obtained from the excellent district sheets of the Lands and Survey Department. But where discrepancies of much moment occurred the streams were carefully resurveyed, the traverses being tied on to trigonometrical points wherever available. In this way the whole of the Upper Arrow and all its branches were measured and observed, and plotted on a scale of 40 chains to the inch ; and much work of this kind was undertaken at Moke Creek, the Twelve-mile Creek, and Skipper's Point.

The report is illustrated with general geological maps and sections of the Soho, Shotover, Skipper's Creek, and Mid-Wakatipu survey districts, a special topographical map of the Upper Arrow and Macetown district, a special large-scale map of Skipper's alluvial goldfield, special plans and sections showing the bathymetrical surveys of Lake Hayes, Moke Lake, Lake Johnson and Lake Kilpatrick, and special plan and sections of the gauging of the Kawarau River Besides these the report is illustrated with numerous photographs and sketches showing the general character of the country and the evidences of glacial erosion that are everywhere so conspicuously impressed on the landscape. Minor rock-structure and vein-formation are shown by diagrams scattered throughout the text.

The general geological maps are printed to a scale of one inch to the mile, and, as in the author's maps of the Alexandra and Cromwell districts, the amount of detail introduced is what was considered necessary to bring out clearly the distinctive features of the geological structure.

The opportunity to show detail with an approach to exactitude is necessarily greatest on large-scale maps. For this reason the special maps of the Skipper's and Macetown goldfields are not mere enlargements of portions of the general maps.

The sections of the one-mile maps are drawn to natural scale, and on these there is unavoidable suppression by superficial deposits. They are always drawn looking towards the north, north-east, or north-west.

General Geological Features.

The prevailing rock in the eastern portion of the district is a soft crumbling mica-schist which is conformably followed by a series of less-altered micaceous rocks, consisting in its upper members of altered greywacke and claystone. The lower and more highly altered schists belong to the Maniototo Series, and the less-altered upper rocks to the Kakanui Series.

The lower schists are distinguished by the presence of numerous bands of chlorite-schist, some of which widen out to extraordinary dimensions in a very short distance.

Bands containing chlorite and chloritoid matter occur sparingly in the lower portion of the Kakanui sub-schists, but they are commonly thin, and seldom continuous for a great distance. At Bob's Cove, on the north shore of Lake Wakatipu, there is a small patch of curiously bent and twisted Miocene marine strata, and from that place there runs a narrow wedge-shaped band of the same Tertiary Series, crossing the mountains to the right branch of the Upper Shotover, being involved along the axis of a great overfold. On viewing this deeply involved bed of fossiliferous Miocene conglomerate on the craggy heights of the Richardson Mountains, the mind travels at once to the wedge of Nummulitic limestone, similarly entangled in the Malm, below the peak of the Silberhorn, in the Bernese Oberland of Switzerland.

One of the important geological features brought out by the author's work in the Cromwell region during the preceding summer was the apparent thickening of the Maniototo schists in proceeding westward from the Dunstan Mountains towards the Arrow and Shotover. The apparent thickening in a distance of some thirty miles was from 12,000 ft. to 30,000 ft., and the problem that remained to be solved was the part played by overthrust-folding in the apparent increase of thickness.

The work of the past summer has more than confirmed the apparent increase of thickness of the Maniototian, and has furnished conclusive proof that the increase is due to overthrust-folding that has been accompanied by horizontal and vertical displacements along thrust-planes running more or less parallel with the strike of the rocks. The course of these overturned folds of schist is marked by the entanglement of wedges of Pliocene lacustrine beds in the Kawarau district,* and of Miocene Tertiaries in the area under review.

The point of greatest scientific interest in this report is the presentation of proof that the Lake Wakatipu region was covered by a continuous ice-sheet of vast depth in the Pleistocene period—a continental ice-sheet that reached to the sea, and probably covered the greater part of the South Island. There is abundant evidence that the glaciation of New Zealand in the Pleistocene attained a degree of magnitude not exceeded in any part of the Northen Hemisphere.

The chains of glacial lakes, the ice-grooved and mammillated slopes of the mountain-ranges, in places terraced to 6,000 ft. and over, the perched erratics, the extensive rock-striation,

* J. Park. Bulletin]No. 5 (New Series), N.Z. Geol. Survey, 1908, pp. 19, 71, 72.

the widespread glacial till—all attest a period of intense refrigeration and prolonged glaciation.

The ice-sheet at the time of maximum refrigeration had a thickness exceeding 7,000 ft. in the Wakatipu basin, forming a vast plateau, above which only the higher peaks appeared like strings of rocky islets in a frozen sea. The existence of a large proportion of foreign material in the till, eskars, and moraines affords graphic and unmistakable evidence of the direction of flow of the ice.

Another point of geological moment is the proof of the comparative youth of our mountains, as shown by the entanglement of Miocene and Pliocene strata along the major faults that run along the axes of the great mountain-chains.

The points of chief economic interest are centred in the development of the gold-bearing lodes at Macetown, Arrow, and Skipper's, in the distribution of the alluvial drifts at these places, and in the utilising of water for irrigation and for the generation of power.

Previous Geological Work.

So far as can be ascertained, the pioneer geological work of Central and Western Otago was that of Dr. Charles Forbes,* of the Admiralty surveying-ship "Acheron," who, in his paper "On the Geology of New Zealand, with Note on its Carboniferous Deposits," made pertinent reference to the geological structure in that region. That was in 1855.

In 1862 Dr. W. Lauder Lindsay discoursed in Dunedin on the mica-schists of Otago, and in the next decade or so there followed papers by Sir James Hector, Mr. James McKerrow, Mr. L. O. Beal, Captain Hutton, and others dealing with the origin of the lake-basins, former glaciation, the origin of the alluvial drifts, and cognate matters. A list of these papers, and of others that bear more or less directly on the Western District of Otago, is enumerated below:—

1. "On the Geology of New Zealand, with Note on its Carboniferous Deposits." Charles Forbes. 1855.
2. "On the Geology of Otago." W. Lauder Lindsay; lecture in Dunedin, 1862.
3. "On Mining in New Zealand." James Hector. Trans. N.Z. Inst., vol. ii, 1869, p. 361.
4. "Notes relative to the Geology of the Manuherikia Valley." James Hector. Otago Prov. Gov. Gaz., 85, Sept. 3, 1862.
5. "Report of Progress of Geological Survey of Otago since 15th April, 1862." James Hector. Otago Prov. Gov. Gaz., 217, 1862.
6. "Geological Explorations to the West Coast of Otago, New Zealand: Report, with Appendix of Meteorological Observations taken on the West Coast of Otago." James Hector. Otago. Prov. Gov. Gaz., 435, Nov. 5, 1863.
7. "Departmental Report of the Geological Survey of Otago"; 13th April, 1864. "Report on the Coals of Otago and other Parts of New Zealand"; Dunedin, 1864.
8. "On the Geology of the Province of Otago, New Zealand." James Hector. Geol. Mag., 233, 1864; Quart. Jour. Geol. Soc., London, vol. xxi, p. 124; Phil. Mag., vol. xxix, p. 157.
9. "Expedition to the West Coast of Otago, New Zealand; with an Account of a Low Pass from Martin's Bay to Wakatipu." James Hector. Jour. Royal Geogr. Soc., London, vol. xliv, p. 96; Proc. Royal Geogr. Soc., London, viii 47, ix 32.
10. "Origin of Rock-basins in New Zealand." James Hector. Geol. Mag., vol. ii, p. 377.
11. "The Glacial Epoch in New Zealand." James Hector. Geol. Mag., vol. vii, p. 95.
12. "Glacial Deposits in New Zealand." Julius von Haast. Nat. Hist. Rev., July, 1864.

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* Quart. Jour. Geol. Soc., London; vol. xi, p. 521.

13. "Notes on the Causes which have led to the Excavation of Deep Lake-basins in Hard Rocks in New Zealand." Julius von Haast. Quart. Jour. Geol. Soc., London, vol. xxi, p. 130; Phil. Mag., vol. xxix, p. 159.
14. "Notes on the Climate of the Pleistocene Epoch of New Zealand." Julius von Haast. Phil. Mag., vol. xxix, p. 398.
15. "Notes on the Rev. J. E. Tenison-Wood's Paper 'On the Glacial Epoch in Australia.'" Julius von Haast. Trans. Royal Soc., Vict., vol. viii, p. 273.
16. "On the Deposition of the Alluvial Deposits in the Otago Goldfields." L. O. Beal. Trans. N.Z. Inst., 1870, vol. iii, p. 270.
17. "On the Date of the Last Great Glacier Period in New Zealand, and the Formation of Lake Wakatipu." F. W. Hutton. 1872. Trans. N.Z. Inst., vol. v, p. 384.
18. "On the Formation of Lake Wakatipu." F. W. Hutton. Trans. N.Z. Inst., 1872, vol. v, p. 394.
19. "On the Cause of the Former Great Extension of the Glaciers of New Zealand." F. W. Hutton. Trans. N.Z. Inst., 1875, vol. viii, p. 383.
20. "On the Geology of New Zealand; with Special Reference to the Drift of that Country." (Abstract.) James Hector. *Nature*, 258, Jan. 27, 1876.
21. "Geology of Otago." F. W. Hutton and G. H. F. Ulrich. Dunedin, 1875.
22. "On the Glacial Action and Terrace-formations of South New Zealand." J. T. Thomson. 1873. Trans. N.Z. Inst., vol. vi, p. 309.
23. "On the Date of the Glacial Period: a Comparison of the Views represented in the Transactions N.Z. Inst., v and vi." A. D. Dobson. Trans. N.Z. Inst., 1874, vol. vii, p. 440.
24. "The Glacial Period of New Zealand." Thomas Mackay. Trans. N.Z. Inst., 1874, vol. vii, p. 447.
25. "Notes on the Ancient Glaciers of New Zealand"; reprinted from Ann. Lyceum Nat. Hist., N.Y., 1876. J. C. Russell. *Nature*, xvi, p. 100.
26. "Notes on Dr. Haast's Supposed Pleistocene Glaciation of New Zealand." W. T. L. Travers. Trans. N.Z. Inst., vol. vii, p. 409.
27. "Remarks on the Cause of the Warmer Climate which existed in High Northern Latitudes during Former Geological Periods." W. T. L. Travers. Trans. N.Z. Inst., 1877, vol. x, p. 459.
28. "Further Remarks." W. T. L. Travers. *Loc. cit.*, p. 470.
29. "On the Formation of Lake Wakatipu." William Stuart. Trans. N.Z. Inst., 1881, vol. xiv, p. 407.
30. "Geology of Canterbury and Westland." Julius von Haast. Christchurch, 1879.
31. "On the Origin of the Old Lake-basins of Otago." (Abstract.) A. McKay. Trans. N.Z. Inst., 1883, vol. xvi, p. 550; and N.Z. Geol. Sur. Reports of Explorations, 1883–84, p. 76.
32. "Otago Lake-basins." A. McKay. N.Z. Geol. Sur. Reports of Explorations, 1883–84, p. 76.
33. "On the District between Dart and Big Bay." James Park. N.Z. Geol. Sur. Reports of Explorations, 1886–87, p. 121.
34. "On the Goldfields of Otago." T. A. Rickard. Trans. Am. Inst. Min. Eng., vol. xxi, p. 441.
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Acknowledgments.

The author wishes to acknowledge his appreciation of the services of his student-assistants, whose zeal and energy aided very materially in the conduct and completion of the work undertaken during the year. The mountainous character of the country, the steepness of the slopes, and the profound nature of the watercourses rendered the field-work extremely tiring and arduous, at all times necessitating the expenditure of a large amount of physical energy. Special acknowledgment is due to Mr. Edward F. Roberts, A.O.S.M., for the care he exercised in the carrying-out of topographical and bathymetrical surveys, and in the compiling and plotting of the maps, plans, and sections; to Mr. Harold Hamilton, for petrographical, bathymetrical, and geological work; and to Mr. C. A. Cotton, M.Sc., and Mr. Frank L. Park, for topographical and geological details.

Much interest was manifested in the conduct of the work by miners and other residents of the districts examined. Useful information and material assistance were given by so many that it would be difficult to name all to whom thanks are due. The author wishes therefore to place on record his warm appreciation of the courtesies offered to himself and party during the progress of the work at the various places that formed centres of operation—notably, Macetown, Arrowtown, Skipper's, Queenstown, Moke Creek, Twenty-five-mile Creek, and Walter Peak Station.

Special acknowledgment is due to Dr. Maclaurin, Dominion Analyst, for the analyses quoted in the text; to Captain R. A. Edwin, R.N., for data relating to the rainfall at Queenstown; to Mr. L. O. Beal, mining engineer, for information relating to the Macetown lodes; to Mr. Richmond Keele, for data in regard to the rise and fall of Lake Wakatipu; and to Mr. William Wilcox, for botanical notes on Wakatipu region.

CHAPTER II.

PHYSIOGRAPHY

Mountains.

This district is occupied by four high mountain-ranges having a general north-and-south trend. They are the Wakefield, Macandrew, Richardson, and Eyre mountains, the three first-named being drained by rivers that flow into the Kawarau River.

The Wakefield Range forms the divide between the Motutapu and Arrow ; the Macandrew Mountains, the divide between the Arrow and Shotover. The Richardson Mountains lie between the Shotover and Lake Wakatipu, but their crest-line is so close to the latter that the bulk of the drainage passes to the Shotover side, the streams draining the Wakatipu slopes being for the most part small, short, and steep. The Eyre Mountains lie on the west side of Lake Wakatipu, and form the barrier between that lake and the Te Anau watershed. Thus we have four mountain-chains, and three dividing-valleys, as under, beginning at the north boundary :—

1. Wakefield Range.

    (*a.*) Arrow Valley.

2. Macandrew Mountains.

    (*b.*) Shotover Valley.

3. Richardson Mountains.

    (*c.*) Wakatipu Valley

4. Eyre Mountains.

The trend and general disposition of these ranges with respect to each other and Lake Wakatipu will be most easily understood by a reference to the sketch shown in Fig. 1.

The Wakefield Range.—This trends north and south, and is the continuation of the main range, of which the Crown Range lying between the Lower Arrow and Cardrona is merely the southern end. It is about twenty miles long, and at its northern end joins the Macandrew Mountains near Mount Motutapu. Its altitude varies from 5,000 ft. to 6,000 ft. above the sea, the culminating point being Mount Soho, an ice-shorn dome-shaped peak which attains a height of 5,743 ft.

About four miles north of Soho there is a depression in the range some 4,000 ft. high, forming a pass over which a bridle-path crosses from the Arrow to the Motutapu Valley. The slopes of the range are everywhere covered with tussock and native grasses, among which the beautiful white gentian (*Gentiana corymbifera*) grows in great profusion, generally at heights between 2,500 ft. and 4,000 ft. Above Macetown the western grass-covered slope, from 2,000 ft. to the summit of the range, is deeply impressed with terraced benches and other marks of ice-erosion.

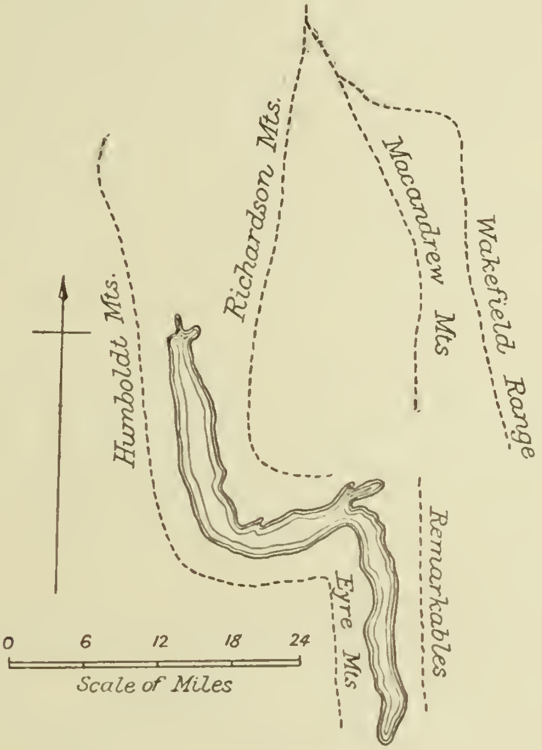

Fig. I. Showing Disposition of Mountain-chains.

The Wakefield Range is so named in honour of that distinguished pioneer and soldier statesman, Captain Edward Gibbon Wakefield, of Nelson.

The Macandrew Mountains.—These consist of a chain of great mountains lying between the Arrow and Shotover. The well-known Coronet Range, which is crossed by the main road to Skipper's Point, is but the southern termination of the Macandrew Mountains, which extend far beyond the limits of this district, forming the divide between the Upper Shotover and Matukituki River. They join the main axial divide at Mount Tyndall, opposite Mount Aspiring, their total length being somewhere near thirty-five miles.

The prominent peaks, beginning at the south end, are the Coronet, 5,400 ft.; Vanguard Peak, 5,799 ft.; Mount Marsden, 4,363 ft.; Advance Peak, 5,700 ft.; Mount St. Just, 5,631 ft.; and Mount Hyde, 5,790 ft., situated near the source of the Arrow River. Lying to the north of Mount Hyde is Mount Motutapu, 6,720 ft., north of which the Macandrew chain rapidly dwindles in width, gathering itself into a single narrow serrated razor-back range that is surmounted by a series of high peaks, among which may be named End Peak, 6,926 ft.; Treble Cone, 6,888 ft.; Black Peak, 7,560 ft.; Niger Peak, 6,616 ft.; and Fog Peak, 6,700 ft.

The eastern slopes of the Macandrew Mountains within our present boundaries are deeply dissected and commonly precipitous—that is, on the outcrop or escarpment side of the strata.

On the reverse or Shotover side the slopes are also excessively steep, being generally uniform with the angle of dip ; but they are smooth and even, and in many places show the terraced and mammillated effects of ice-erosion in a wonderful state of preservation.

The immunity which the western slopes of the mountain-chains traversing this region have till now enjoyed from pluvial dissection is due to the circumstance that the summit-line is so close to the trunk rivers in the case of the Wakefield and Macandrew Mountains, and to Lake Wakatipu in the case of the Richardson Mountains, that the gathering-ground is too small and restricted in area to permit the formation of large streams The streams that now exist, or, rather, the stream-channels, are mostly narrow gutters, fairly straight, with a V-shaped cross-section, and a bottom that commonly has the same pitch or inclination as the mountain-slope.

The Macandrew Mountains have been named after the late Mr. James Macandrew, one of Otago's most distinguished statesmen and pioneers.

The Richardson Mountains.—These include Ben Lomond and Bowen Peak, overlooking Queenstown, and the confused chain of ice-shorn mountains stretching northward between the Shotover and Lake Wakatipu. They also form the divide between the Shotover and the Rees rivers, and, sweeping northward from Mount Aurum, join the main axial divide at Mount Edward, 8,459 ft. The highest peaks, beginning at the south end, are Ben Lomond, 5 747 ft. ; Bowen Peak, 5,322 ft. ; Mount Gilbert, 5,775 ft. ; Mount Crichton, 6,185 ft. ; Ben More, 5,987 ft. ; Mount Larkins, 7,432 ft. ; Mount Hamlet, 7,200 ft. ; Stone Peak, 7,222 ft. ; Mount Aurum, 7,315 ft. ; Centaur Peak, 8,284 ft. ; Mount Cunningham, 7,681 ft.

The Lake Wakatipu or western slopes of these mountains are in many places deeply grooved, terraced, and ice-shorn by the ice-sheet that flowed down the Wakatipu Valley. A lateral stream of the great glacier flowed into the head of Moonlight Creek by what is now known as the Twenty-five-mile Creek, and two streams crept into Moke Valley, one by the Lake Dispute Valley and one by the Five-mile Creek, both streams uniting at Moke Lake which is more accessible from Lake Wakatipu than from Moonlight Creek, the trunk stream into which it drains.

The Eyre Mountains.—The portion of these mountains lying within the Queenstown Subdivision comprises Cecil Peak, 6,477 ft. ; Walter Peak, 5,956 ft. ; and Mount Nicholas, 4,827 ft. The slopes of Cecil Peak, lying opposite Queenstown, from the level of the lake to a height of nearly 6,000 ft. are finely grooved and rounded by ice-erosion. Mount Nicholas is a conspicuous dome-shaped elevation lying between the Von River and the Afton Burn. It lay right in the track of the great Von Glacier, and its smooth, rounded summit and equally smooth slopes are the result of long-continued ice-erosion. The Eyre Mountains run first north-and-south, then trend west, and opposite the upper reach of the lake, under the name of the Humboldt Mountains, once more run north-and-south.

Origin of Mountain-chains.

An examination of the country lying between the Arrow and Lake Wakatipu shows at once that the origin of the great parallel mountain-chains described above is the result of close folding of the rock-formations. From the Arrow to the Eyre Mountains the strata have a simple continuous dip towards the west, the general trend of the ranges being more or less parallel with the axis of the overturned folds and shear-planes.

On the other hand, the existence of powerful faults traversing the main valleys has been well established, and there seems to be no serious difficulty in believing that these mountain-chains as we now see them owe their origin to great dislocations along the axes of the over-folds and shear-planes, in which fluviatile and glacial action, acting singly or in concert, have excavated the present narrow rift-like dividing valleys

Thus we find that the comparatively flat-lying schists were pushed by tangential stress into great folds running nearly north-and-south. In the troughs of the folds there were entangled strips of Pliocene and Miocene strata. The stress from the west exceeded that from the east, thus overturning the folds. When the folds were closed the progressive tangential stress was relieved by the shearing or sliding of one fold over the other, the shear-planes being more or less parallel to the axis of the major folds. Along the shear-planes the rocks were more shattered and dislocated than elsewhere. They were lines of weakness, and along their course fluviatile action became most active, and in time established the present trunk valleys. In other words, the mountain-chains of the main divide are tectonic; and the dividing valleys areas of fluviatile erosion, following for the most part the axes of overfolds, the troughs of which are traversed by thrust-planes of great magnitude.

In the following diagrammatic section are shown the four mountain-chains, the Arrow and Shotover faults, the great Wakatipu fault that runs along the upper reach, and the westerly dip of the strata :—

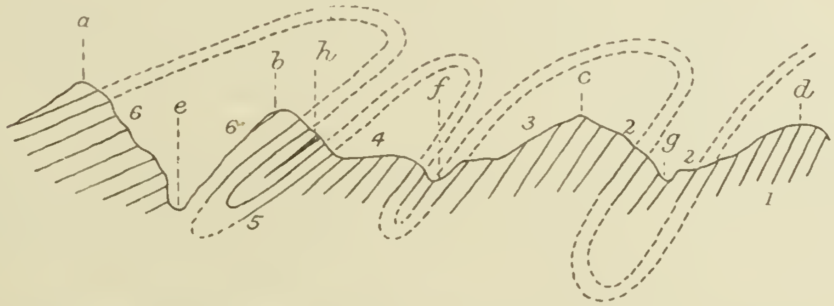

Fig. 2. Showing Mountain-chains and Faults in the Arrow, Shotover, and Wakatipu Valleys.

(*a.*) Humboldt Mountains. (*b.*) Richardson Mountains. (*c.*) Macandrew Mountains. (*d.*) Wakefield Range. (*e.*) Lake Wakatipu. (*f.*) Shotover Valley and fault. (*g.*) Arrow Valley and fault. (*h.*) Wedge of involved Tertiaries.

1. Mica-schist. 2. Chlorite-schist. 3 and 4. Mica-schist. 5. Slaty mica-schist. 6. Altered greywacke.

The Arrow fault is plainly discernible, inasmuch as it causes a repetition of the great chlorite-schist bands that are so prominent a feature of the geological structure below and above the junction of the Arrow and Soho streams.

The Shotover fault runs along the floor of the alluvial gold-mining claims situated on the high terrace on the west side of the valley between Skipper's Point and Maori Point. It is a feature well known to the local miners, being commonly named the "Pug lode." It crosses the Shotover a short distance below the mouth of Long Gully, and thence passes southward in an almost straight line across the shoulder of Coronet Range to Arthur's Point. Going northward it crosses the Skipper's Creek near the mouth of Butcher's Gully, and thence proceeds northward to the junction of the Right Hand Branch of the Shotover.

The Arrow and Shotover fault-planes formed initial lines of weakness, and it may be reasonably contended that they were marked by depressions that would in time become deepened and widened by the trunk river following the zone of dislocation. It is obvious that the main valleys were formed, and the great drainage-systems of the present day established, some time before the advent of the Pleistocene glacial period. The advancing ice-sheet, with its tongue-like prolongations, in course of time, by continuous grinding and digging, still further deepened and widened the trunk valleys, leaving their slopes grooved, rounded, mammillated, and terraced as we now see them.

Rivers and Valleys.

Kawarau River.—The Kawarau drains Lake Wakatipu, and, even at the outlet, at what is known as the "Kawarau Falls," is a river of majestic and imposing size. The streams draining the slopes of the Eyre and Richardson mountains flow into Lake Wakatipu, and, since the Shotover and Arrow flow directly into the Kawarau, it is seen that the Kawarau carries the whole of the drainage of the region dealt with in this report.

The author, by a number of approximate measurements made near Cromwell during the summer of 1906–7, computed the average summer flow of the Kawarau* at 10,500 cubic feet per second. More exact gaugings made in March of the present year, at a time when the river was at about mean summer-level, gave a flow of 13,417 cubic feet per second. The details of these last measurements and gaugings will be found in the chapter on "Hydrology."

Shotover River.—This is the largest tributary the Kawarau receives anywhere in its course, from its source to its confluence with the Clutha at Cromwell. It drains the western slopes of the Macandrew and the eastern slopes of the Richardson mountains, and is mainly snow-fed. Its flow is subject to great variation, more especially in spring and early summer, being influenced in these seasons by warm winds and rains acting on the already melting snows of winter. When gauged on the 9th March the flow of the Shotover above Skipper's Point amounted to 360 cubic feet per second. In times of high flood this flow is increased twenty or perhaps even thirty fold.

The Shotover joins the Kawarau at right angles to the course of the latter, and, when in flood, by reason of its great volume and velocity of entry, obstructs the flow of the Kawarau, which, being unable to spread itself, owing to the great height of its banks, is thus partially dammed back, its waters on occasion rising so high as to flood and obliterate the rapids at the outlet of the lake. On such occasion there may be seen the rare spectacle of water running into, instead of out of, Lake Wakatipu.

The Shotover runs close under the foot of the Macandrew Mountains, and consequently receives no feeders of any moment from that side. On the west side it is joined by Moonlight, Stony, Skipper's, Right Hand, and other large streams, which, with their numerous branches, have dissected the eastern side of the Richardson Mountains into a maze of picturesque tent-shaped ridges, whose gable-like ends rise one above the other in ascending tiers until the summit of the main divide is reached.

The Right Hand Branch, Skipper's, and Stony creeks, although so widely separated at their confluence with the Shotover, all rise on the slopes of Mount Aurum, and enclose within their watershed an area that for the height of its ridges and steepness of contour is perhaps without a parallel in New Zealand. The ridges are tent-shaped, and separated by V-shaped gorges that are seldom more than a few yards wide at the bottom.

The existence of these wonderful tent-shaped ridges that present their gable ends to the Shotover is to be explained by the circumstance that the country rock is a soft crumbling mica-schist with a continuous dip to the westward, cut transversely by the lateral streams that drain into the Shotover. And there is indubitable evidence that this profound erosion and dissection have taken place since the glacial period—that is, in the geological yesterday. On the ends of the steep gables facing the Shotover there are still to be seen the remains of the horizontal or gently flowing ice-cut rock-benches that marked the western slopes of the Shotover glacial valley. These ice-shorn remains are well seen when standing on the main road between the mouth of Stony Creek and Maori Point and looking westward.

The Shotover River, from some miles above the junction of Skipper's Creek to a point a mile below Arthur's Point, runs in a narrow rock-cut channel or gorge that is excavated 200 ft.

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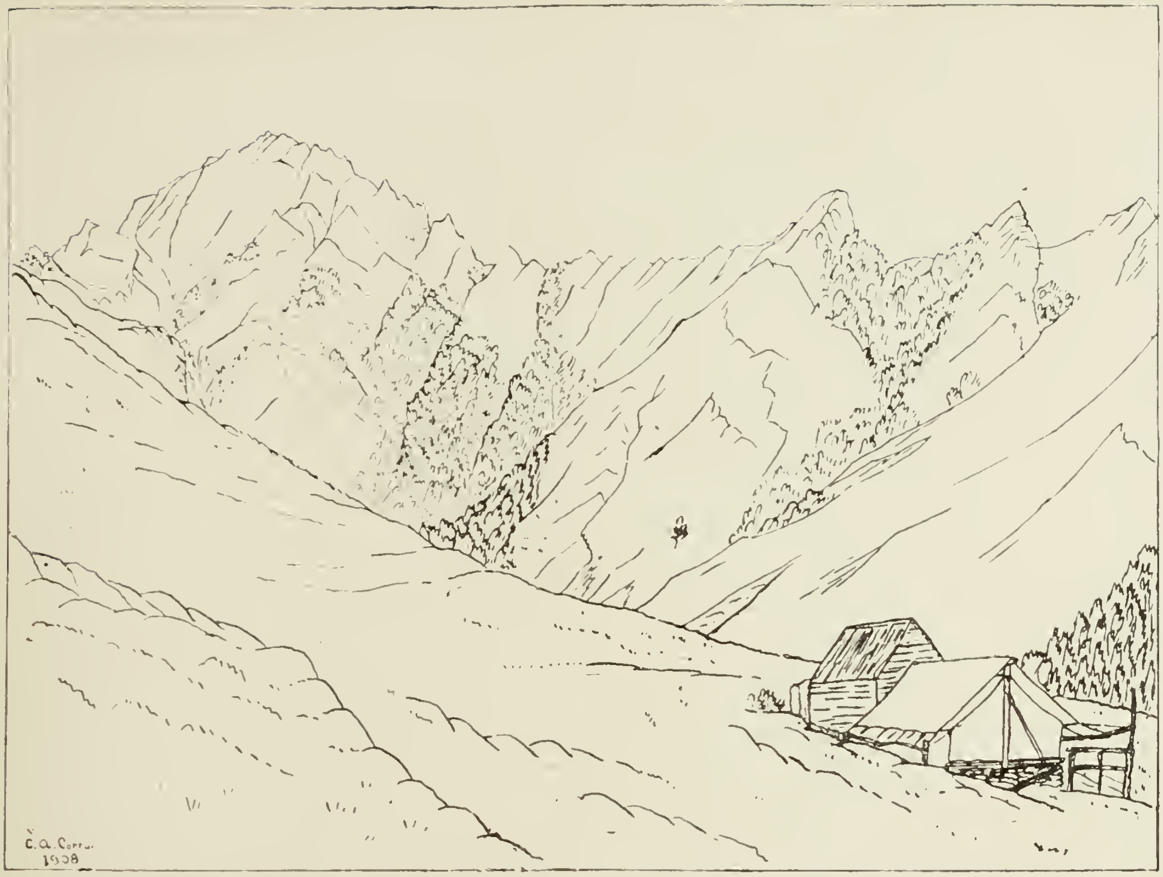
* James Park. Bulletin No. 5 (New Series), N.Z. Geol. Sur., 1908, p. 22.



Gabled Ridges eroded since Glacial Period.

Looking up the Arlow Gorge.

PLATE IV.

Photo lent by Tourist Dept.]

Shotover Bridge, on Road to Arrowtown.

Old Hanging-valley of Arrow River.

Photo James Park.]

Ice-shorn Tor and Crag on Skipper's Road.

Photo Miles Aspinall.]

PLATE VI.

ON CORONET RANGE, ROAD TO SKIPPER'S POINT.

Photo lent by Tourist Dept.]

PLATE VII.

SHOTOVER GORGE, ON ROAD TO SKIPPER'S POINT.

Photo lent by Tourist Dept.]

PLATE VIII.

Shotover Gorge at Arthur's Point Bridge.

PLATE IX.

Bullendale Creek, Skipper's, showing Profound Erosion of Features since Glacial Period.

Photo James Park.]

below the floor of the old glacial valley. The sides of this gorge are so steep that the river can only be reached with safety in a few places along the whole of its course.

The floor of the old glacial channel, lying, as we have seen, about 200 ft. above the present river-level, is also excavated in the solid rock, in many places being sharply defined with vertical walls and an even pavement-like floor.

After the retreat of the glacier the outlet of the valley became temporarily blocked, thus causing the Shotover and its tributaries to cover the floor of the glacial valley with gravels to a depth of 200 ft. The river-terraces between Skipper's Point and Maori Point are the remains of this old flood-level.

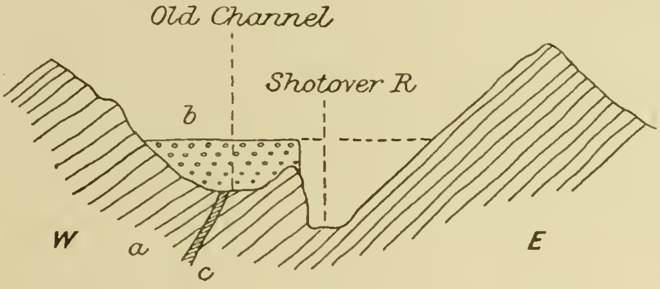


Fig. 3. Section across Shotover Valley, showing High-level Terrace-gravels lying on Floor of old Glacial Channel.

(*a.*) Mica-schist. (*b.*) Terrace-gravels. (*c.*) Shotover Fault, locally known as the " Pug Lode."

The largest tributary of the Shotover is Moonlight Creek, with a summer flow of about 52 cubic feet per second. It cuts back almost to the west side of the Richardson Mountains, taking its rise in Lake Luna, which is separated from the Twenty-five-mile Creek, draining into Lake Wakatipu, by a distance of only a few hundred yards. The main branch of Moonlight Creek is Moke Creek, carrying a summer flow of some 24 cubic feet of water per second. It rises in Moke Lake, which is easily accessible from Lake Wakatipu by two glacial valleys —namely, the one in which Lake Kilpatrick lies, and the other occupied by Lake Dispute, which is drained by the Nine-mile Creek.

Next to Moonlight in size comes Stony Creek, carrying a summer mean flow of 28 cubic feet per second, and after it Skipper's Creek, of historic fame for the richness of both its gold-bearing drifts and gold-bearing veins. Skipper's is a considerable stream, carrying a summer flow of about 15 sluice-heads, or 15 cubic feet, per second.

Arrow River.—The course of this river from its junction with the Kawarau to Arrowtown, a distance of four miles, is nearly due north, passing along the foot of the Crown Terrace. At Arrowtown it turns sharply to the north-east, its course pursuing this direction until the junction of the Soho or Roaring Billy is reached. In this distance, which is some four miles, the river runs through a steep narrow gorge. At the mouth of the Soho the Arrow Valley trends north-west until Macetown is reached—a further distance of five miles. Above Macetown the trend is north-north-east. From Arrowtown to the Soho the Arrow follows the course of a powerful fault which also passes up the valley of the Soho itself, a continuation of the middle reach of the Arrow.

At Macetown the Arrow is joined by the Goldburn, a stream on which is situated the well-known Premier, Tipperary, and other mines. Below the junction of the Goldburn at Macetown, the flow of the Arrow on the 15th November, 1907, amounted to 80 cubic feet per second, and above the junction to 65 cubic feet. This would give a flow of 15 cubic feet for the Goldburn. The Arrow and the Goldburn are mainly snow-fed, and their mean summer flow is much less than the flow in spring.

From the Kawarau junction to Macetown, the bed of the Arrow River rises a height of 700 ft. in some fourteen miles. By lifting the river at a point half a mile below the Soho junction, a valuable supply of water could be obtained for motive power and irrigation, the available head being sufficient to command the greater part of Arrow Flat. The scheme is one of no great cost, and presents no engineering difficulties whatever. The distance of the pipe-line from the inlet to Arrowtown would not exceed three miles and a half.

The present gorge of the Arrow is merely a narrow notch cut in the floor of the old glacial valley which formerly stood at the level of the Crown Terrace, and was therefore at the close of the glacial period a hanging-valley lying some 750 ft. above the Arrow Flat, which it overlooked. Even now there is no difficulty in tracing the outline of the old valley. The western slopes of the Crown Range behind Mount Beetham are still distinctly marked with ice-cut terraces and benches up to a height of 5,500 ft. ; and on the west side, notwithstanding the deep sculpturing of the slopes effected by the streams descending from the Coronet Range, there are still to be seen remnants of undulating or horizontal glacial benches up to 3,000 ft. above the floor of the present Arrow Valley.

Lakes.

Lake Wakatipu.

The Mid-Wakatipu Survey District includes that portion of Lake Wakatipu lying between Queenstown and the Twenty-five-mile Creek on the north, and between Cecil Peak and Mount Nicholas on the south side. The lake consists of three main reaches, the upper and lower of which lie in an almost north-and-south line. The middle reach runs nearly east and west.

The extreme length of the lake, measured along the centre-line, is a little under fifty miles. The width varies from 1·5 to 3·3 miles, the mean breadth being 2·3 miles. The shore-line is remarkably regular, being broken only by Frankton Arm and Bob's Cove. The bays are merely shallow indentations, while none of the promontories extend far beyond the general coast-line.

The lake has an area of 112 square miles, exclusive of the group of small islands lying near the north end.

The surface of the water has a yearly range in level, according to Mr. R. Keele, of 4 ft. 8 in. between the maximum summer and minimum winter levels. The mean height of the surface of the water is 1,015 ft. above sea-level, checked by the railway levels at Kingston.

In reply to the author's inquiries, Mr. Richmond Keele, the Postmaster at Queenstown, writing under the date of the 8th May, 1908, courteously supplies the following information with respect to the yearly rise and fall of the lake : The lake, he says, " as a rule rises once in the year to the 6 ft. level on the gauge-board attached to the jetty ; sometimes twice. On one occasion I have seen it reach the 6 ft. 6 in. mark, and on the other hand I have seen it fall to the 11 in. mark above what is called the *normal mark*, which is, I believe, a line laid down many years ago when the lake happened to be very low. During the past twelve months the lake rose to the 6 ft. 3 in. level and fell to the 1 ft. 2½ in. level, a difference of 5 ft. ½ in. between the highest and lowest readings. For the twelve months previous the highest level reached was 6 ft. 1 in., and lowest 2 ft. 1 in., giving a difference of 4 ft. During the year prior to the last quoted the highest level was 5 ft. 11 in., and the lowest 1 ft., a difference of 4 ft. 11 in. The average yearly range is probably about 4 ft. 8 in."

PLATE X.

KAWARAU FALLS, LAKE WAKATIPU OUTLET.

Photo P. Malighan.]

[*To face p. 15.*

The lake is bordered by the Remarkables and Richardson mountains on the north side, and by the Eyre and Humboldt mountains on the south side. These mountains lie so close to the lake that their slopes are extremely steep, in many cases rising from 5,000 ft. to 6,000 ft. above the lake in a horizontal distance of two or three miles.

The catchment-area of the lake is about 1,200 square miles in extent. It is bounded on all sides by ranges that attain a height varying from 5,000 ft. to 9,000 ft., and carry a large amount of snow during the greater part of the year. The northern end of the Humboldt and Richardson mountains and Mount Earnslaw and Forbes Mountain maintain extensive snow-fields throughout the whole year; hence the Dart and Rees rivers, draining these, supply the bulk of the water flowing into the lake. The only other considerable streams flowing into the lake are the Greenstone, Von, and Lochy rivers, draining the Humboldt and Eyre mountains. The Remarkables (6,000 ft. to 7,600 ft.), lying between Kingston and Queenstown, rise so abruptly from the shores of the lake that they contribute practically nothing to the catchment-area, being too steep to afford a footing for other than a thin veneer of winter snow, which disappears with the first appearance of spring.

The Eyre Mountains (5,000 ft. to 6,500 ft.), fringing the opposite side of the lake, in that portion of them lying between Kingston and Mount Nicholas, lie so close to the water's edge that their contribution to the drainage is very small, none of the streams carrying more than a few cubic feet of water per second, with the exception of the Lochy, the mean summer flow of which does not exceed 25 cubic feet per second.

The crest-line of the Richardson Mountains (5,000 ft. to 7,500 ft.), from Queenstown to Glenorchy, also lies so near the lake that the slopes are drained by a number of small brooklets that dry up in summer or carry only a few sluice-heads of water. The only exceptions to this, in a distance of thirty-five miles, are the Twelve-mile Creek, with a minimum summer flow of 10 cubic feet per second, draining a permanent snow-field on the south face of Mount Crichton; the Twenty-five-mile Creek, with a flow of 7·5 cubic feet, draining the slopes of Ben More; and Bucklerburn, with 20 cubic feet, descending from Mount Aurum.

The Origin of Lake Wakatipu Basin.

Lake Wakatipu lies in a rock-bound basin. The surface of the water is 1,015 ft. above the sea, and its maximum depth is 1,242 ft.,* giving the point of greatest depth at 227 ft. below sea-level.

The height of the rock-rim at the south end of the lake near Athol is about 850 ft. above the sea, or 165 ft. below the present level of the lake. From this it will be seen that Lake Wakatipu as it now exists is partly rock-bound and partly barrier-bound, the barrier being the great moraine at Kingston. The present outlet at Kawarau Falls is over a ragged rim of rock about 1,000 ft. above sea-level.

The first recorded attempt to explain the origin of Lake Wakatipu was made by Sir James Hector, who, in one of a series of lectures "On Mining in New Zealand" delivered at the Colonial Museum, Wellington, in the year 1869, ascribed the formation of the lake to differential subsidence.† In the following year Mr. James McKerrow,‡ who possessed an intimate knowledge of the lake and its bordering mountains, having for some years prior to this been engaged in the topographical and geodetic survey of this region, ascribed the origin of the lake to glacial erosion, supporting his contention with all the cogency of many carefully observed facts.

* Keith Lucas. "The Geographical Journal," June, 1904, p. 753.

† James Hector. Trans. N.Z. Inst., vol. ii, p. 374.

‡ James McKerrow. "On the Physical Geography of the Lake District of Otago." Trans. N.Z. Inst., vol. iii, p. 254.

Captain Hutton,* in 1872, in a paper "On the Formation of Lake Wakatipu," states his complete agreement with Mr. McKerrow, and at the same time shows the many difficulties that lie in the way of acceptance of Hector's theory of unequal subsidence. Again in 1875 he still maintains his adhesion to the theory of ice-erosion,† in doing so following the lead of the distinguished Sir Andrew Ramsay, who, by his brilliant work in glaciology, was the first to show that almost the whole of Britain had been covered with a continuous ice-sheet. Ramsay was also the first to perceive the competency of a valley-glacier to excavate its floor so as to form a true rock-basin. From the early fifties till his death he consistently maintained this view, which in later years has received emphatic support from such eminent geologists as Sir Archibald Geikie, Professor James Geikie, Professor Heim, and Professor Penck. Tyndall, the physicist, whose investigations of the Alpine glaciers of Europe form a monument of patient and painstaking research, also held views of glacier-erosion similar to those of Ramsay.

Mr. Alexander McKay,‡ in a paper "On the Origin of the Old Lake-basins of Otago," read before the Wellington Philosophical Society in 1883, reviews the differential subsidence and ice-excavation theories of rock-basin origin, and gives his adhesion to the former. Professor Cox, in the discussion which followed, disagreed with Mr. McKay, believing that the old lake-basins had been to a large extent excavated by ice.

The author, after an investigation of the numerous evidences of intense glaciation presented in this district, is of the opinion that the origin of Wakatipu rock-basin is partly due to subsidence caused by faulting and partly to ice-erosion. A discussion of the competency of glacier-ice to excavate basins will be found in the chapter devoted to "Glaciation."

Glacial Lake Wakatipu.

The tiers of old lake-beaches, seven or more of which can be distinctly traced in different places around the present shore-line, rise to a height of 150 ft. above the present lake-level, and afford convincing proof that the surface of the lake at one time stood much higher than it now does. The old beaches are nearly always composed of small biscuit-shaped pieces of mica-schist of fairly uniform size. They are in all cases unconformable to the glacial drifts and morainic matter on which they rest, as, for example, at Queenstown, at the Five-mile Creek, and other places.

The old beaches contain little morainic or foreign ice-borne material, nor are they overlain by glacial drift, from which it may be inferred that it was after the recession of the glacier that the lake stood at the higher level.

It is a noticeable feature of the old beaches that the highest one is often bounded by an even line of steep scarp or cliff, such as may be seen on any shore-line of the present day. Even when the top beach is so fringed it is commonly composed of the usual yellowish-brown biscuit-shaped shingle, but not everywhere. In places between the Five-mile Creek and Queenstown, and from Frankton southward along the lake-face of the peninsula, the 150 ft. beach is found to be excavated in the solid schist. Perhaps it would be more correct to say that the rocks have been eaten into rather than excavated by the action of the water, which appears to have remained at this level for a considerable time. It is just probable, although there is no proof of it, that the eating-away of this old strand was in part the work of floating masses of ice. Alternating frost and thaw, by shattering and crumbling the rock, would also afford the water effective help in the work of erosion.

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* Captain Hutton. Trans. N.Z. Inst., vol. v, p. 394.

† Hutton and Ulrich. "Geology of Otago," Dunedin, 1875, p. 87.

‡ A. McKay. Trans. N.Z. Inst., vol. xvi, p. 550; and N.Z. G.S. Reports of Explorations, 1883–84, p. 76.

When the waters stood at the 150 ft. contour Lake Wakatipu covered a much larger area than it now does. The Domain at Queenstown, Frankton Flat, and a large part of the peninsula were submerged, while all the low-lying land in the lower Shotover and Arrow were within the limits of the glacial lake, as also was Lake Hayes and all the low ground in its vicinity. The lake extended from the Kawarau Falls along the foot of the Remarkables, thus isolating the Crag-and-Tail Hill, which then stood out of the water as a steep ice-worn island. In other places there was little change in the size or form of the lake on account of the steepness of the land, except at the upper end, where the waters extended far up the Dart and Rees valleys, and ramified along the floor of all the lateral streams.

The form of the present and glacial lakes is shown in the next two figures.

Figs. 4 and 5. Showing the Present Form of Lake Wakatipu and of the Glacial Lake respectively, on a Scale of Twelve Miles to an Inch

Lake Hayes.

This is a picturesque sheet of water situated on the main coach-road to Arrowtown. The upper end is about two miles from Arrowtown, and the lower about eight miles from Queenstown. Its length is somewhat under two miles, and its breadth varies from 30 to 50 chains. It covers an area of 655 acres, and its surface lies 1,080 ft. above the sea. The greatest depth is 108 ft., found at a point about 75 chains from the upper end and 15 chains from the west side.

The floor is almost flat for nearly a mile in length, and lies below a depth of 100 ft. The trend of the line joining the inlet and outlet is north-and-south (magnetic).

The lake presents an almost unbroken shore-line, deep bays or sharp promontories being entirely absent. It lies in a rock-basin, the rim of which is only some 14 ft. below the surface of the water. On the east and west sides the lake is bounded by gently undulating, ice-planed, terraced hills composed of mica-schist, and at the upper end by a low alluvial flat, not many feet above the level of the water. The flat is in its turn bounded by a terrace composed mainly of finely bedded silts and rock-flour.

The south end of the lake is fringed by a marshy flat reaching to the edge of the coach-road, and behind this flat—that is, between the lake and the Kawarau River—there is a high alluvial terrace composed of excessively fine silts or rock-flour intercalated with beds of a soft grey calcareous ooze that has been found to be of great value as a fertiliser. A detailed description of this calcareous deposit, locally called "limestone," will be found in the chapter devoted to "Economic Geology."

The terraces fringing the lake on the west side are partly rock-cut and partly fragmental. These terraces are old high-level beaches that mark the successive levels of the lake after the retreat of the ice-sheet. The topmost beach corresponds with the highest of the old beaches contouring round the shore of Lake Wakatipu, and indicates the flood-level at the time Lake Hayes formed part of glacial Lake Wakatipu.

Moke Lake.

This lake lies at the source of Moke Creek, at a height of 1,710 ft. above the sea. It is distant some nine miles from Queenstown, and is most easily accessible by way of the Five-mile Creek, flowing into Lake Wakatipu. This stream runs back to a low saddle in an ice-excavated valley, from which is a gentle descent to Moke Lake. The lake can also be reached by way of Arthur's Point and Moonlight Gorge, a journey of twelve miles; or by the Nine-mile Creek and Lake Dispute, and thence up the ice-shorn valley to the low saddle above, whence there is a gentle descent to Moke Lake.

This lake lies in a basin surrounded with beautifully ice-planed ridges and mountains. It is shaped like a horse-shoe, its unusual form being due to the circumstance that it lies in two rock-basins that join at their lower end. Twin lakes like Moke Lake are not unknown in the glaciated regions of Northern Europe and North America.

The lake at one time extended down to the upper end of the Moke Gorge, but the Right Hand Branch of Moke Creek and the mountain-torrents descending from Ben Lomond have filled up the lower end with detritus. The fan of a stream descending from Ben Lomond has also filled in a considerable area of the eastern arm—nearly 30 acres in extent—thereby destroying the continuity of the shore-line of the old glacial lake.

The area of the lake is 240 acres. The length of the east arm is 63 chains, of the west arm 70 chains, while the greatest width of the united arms is 46 chains.

The two arms of the lake are separated by a narrow tussock-covered ridge that has been worn down to a low sharp point, called Wedge Point, at the meeting-place of the two glaciers that excavated the basins (see Plate IX). The greatest depth of the lake is 145 ft., found a short distance off Wedge Point.

The planting of carefully selected sorts of trees on the flats and fans would greatly enhance the beauty and attractiveness of this place as a tourist resort.

Lake Kilpatrick.

This is a small tarn situated in the glacial valley in which lies the eastern arm of Moke Lake. It is 18 chains long, and varies from 3 to 8 chains in width. Its area is 10·5 acres. Soundings disclosed the fact that it is quite shallow, the depth nowhere exceeding 12·5 ft. The bottom is covered with submerged logs of timber, mostly those of beech. This lake lies about 80 ft. above Moke Lake, or at a height of 1,790 ft. above the sea.

Lake Johnson.

This occupies a small rock-basin at the north end of Queenstown Hill. It is about a mile and a half from the head of Frankton Arm and half a mile from the Shotover. It lies at a height of 1,285 ft. above the sea. Its length is 45 chains, and mean width 14 chains. The area is 70 acres. The greatest depth was found to be 88 ft.

MOKE LAKE (GLACIAL TWIN LAKE).

Photo James Park.]

LAKE DISPUTE, LOOKING TOWARDS LAKE WAKATIPU.

Photo James Park.]

PLATE XII.

ICE-TERRACED SLOPES OF BEN MORE, LOOKING ACROSS LAKE LUNA.

Photo James Park.]

The rock-rim at the lower or outlet end is 55 ft. below the summer water-level of the lake, as shown in the following diagram :—

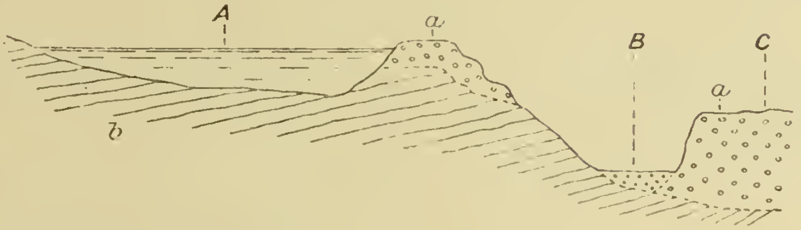


FIG. 6. SHOWING LONGITUDINAL SECTION OF LAKE JOHNSON, WITH ROCK-RIM AND GRAVEL BARRIER.
A. Lake Johnson. B. Shotover. C. Shotover Flat. *a*. Pleistocene Gravels. *b*. Mica-schist.

Lake Dispute.

This is another rock-basin lying in a narrow ice-excavated valley at the head of Nine-mile Creek. It is a little over a mile long, and varies from 4 chains wide at the lower end to nearly 15 chains wide near the upper end. Its area is between 60 and 70 acres. No soundings were taken of this lake, as it was found impracticable to get a boat on to it. However, it is improbable that the depth anywhere exceeds that of Moke Lake, and the probability is that it is much shallower. Its catchment-area is very small, being under four square miles. The summer flow of its outlet is about 2·15 cubic feet per second. (See Plate XI.)

Lake Luna.

This lake is situated at the head of Moonlight Creek, at the extreme north end of Mid-Wakatipu Survey District, and all but the south end of it lies in Glenorchy Survey District. Its surface is 2,620 ft. above sea-level. It occupies a rock-basin in the floor of a narrow glaciated valley that extends back to the Twenty-five-mile Creek, from which it is separated by a low saddle.

The greatest length of the lake is about a mile and a quarter. The width varies from a few chains at the south end to about 20 chains near the lower end. The flow of water from the outlet amounted to 4·25 cubic feet per second on the 24th March of this year.

Lake Luna can be most easily reached from the Twenty-five-mile Creek, that flows into Lake Wakatipu about three miles below the south end of Pig Island, either by crossing a pass 4,400 ft. high in the Richardson Mountains, at a point some four miles past the Twenty-five-mile Creek, or by following up the course of the Twenty-five-mile itself. The journey by either route takes about four hours.

The lake lies at the foot of Ben More, 5,987 ft., the western slope of which has been deeply grooved, from the level of the lake to the summit of the range with the most remarkable and best-preserved series of glacier-benches to be found in the Wakatipu district or elsewhere in New Zealand. These ice-cut terraces are shown very well in Plate No. XII. They vary from 30 ft. to nearly 70 ft. in height, and from a few yards to over 2 chains in width. They are excavated in a fairly hard quartzose mica-schist. The broader benches often have an undrained depression at the back, generally close under the slope ascending to the next platform. Altogether some thirty rock-benches can be counted on the mountain-slope above the lake, and it is not a little singular that a like number can be traced, although not so clearly, on the western grass-covered slopes of the Remarkables, between Kingston and Staircase Gully, and on the eastern slope of Cecil Peak, facing Queenstown.

As shown by the distribution of the foreign transported material, the flow of ice was from Lake Wakatipu, up the valley of the Twenty-five-mile, and thence down the valley of Moonlight Creek. The glacier-benches, as may be gathered from a perusal of Plate XII, slope gently upward at the lower end of Lake Luna, this upward slope being doubtless that taken by the ice-plough after excavating the rock-basin near-by.

Rock-benches corresponding to those on the north-east side of Lake Luna can also be traced on the opposite side of the lake—that is, on the eastern slopes of the Richardson Mountains—but they are not so well preserved as those just described, having been cut through in many places by small lateral streams and gullies.

What is shown on the Mid-Wakatipu District Sheet of the Lands and Survey Department as a large lagoon was found to be a small rock-tarn, some 6 chains by 4 chains in size, draining into the Twenty-five-mile. It has been excavated in the floor of the old glacial valley, the present deep V-shaped gutter in which the Twenty-five-mile runs being a feature of comparatively recent date.

Great Faults.

There are six powerful faults in the area examined that have either a structural importance or have exercised an influence in determining certain prominent physical features. They are the Arrow, Soho, Shotover, Moonlight, Queenstown, and Kawarau faults, all of which are indicated on the map facing this page.

Arrow Fault.—This crosses the Crown Range and traverses the course of the Upper Arrow from the junction of the Soho to Macetown, whence it follows the valley of the Goldburn to the saddle on the Macandrew Range lying immediately west of Advance Peak, whence it passes into the Upper Shotover Valley, which it reaches about a mile above the mouth of Rapid Creek.

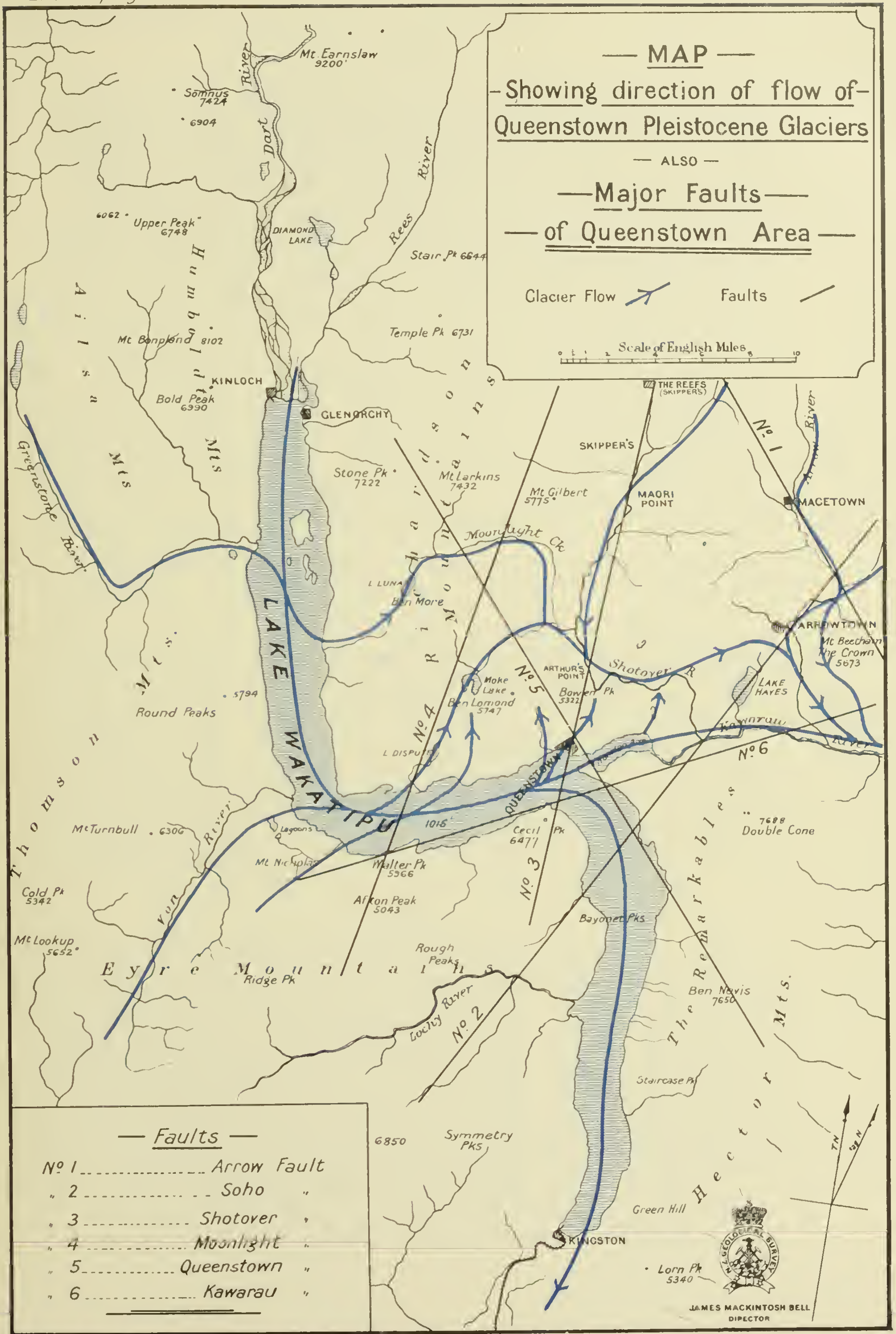
The general course of this fault is north-west and south-east. Its distinctive feature is the manner in which it causes a repetition of the great chlorite-schist band of the lower Arrow.

Soho Fault.—This fault crosses the Crown Range and passes down the Soho to the Arrow, which it follows to a point lying between Arrowtown and Mount Beetham, whence it crosses the Arrow Flat, pursuing a south-west course which carries it along the east side of Lake Hayes, where its path is well marked. It crosses the Kawarau River a short distance below the mouth of the Shotover, and thence traverses the valley that lies between Peninsula Hill and the Remarkables, eventually reaching the shore of Lake Wakatipu at Drift Bay, which lies a little south of Jack's Point.

This great fault hades towards the north-west at angles varying from 35° to 50°. It follows a line of depression throughout its course, the Soho and Arrow valleys, Lake Hayes, and the lower arm of Lake Wakatipu lying in its track. To what extent these basins are due to faulting is, of course, a matter of mere conjecture, but that the Soho fault formed a line of dislocation which offered favourable conditions for the operation of fluviatile and glacier erosion is a conclusion that seems to be warranted by the existing circumstances. The lower arm of Lake Wakatipu is doubtless to some extent a rift-valley, as may be judged from the dislocation of the schists on the two sides of the lake, caused partly by this fault and partly by the Shotover fault.

Shotover Fault.—This is locally known as the "Pug lode." It was first identified in the terrace claims near Skipper's Point. Its course is about 5° east of true north, and it inclines to the west at angles that are rarely under 70°.

From Skipper's Point, going northward, it crosses into Skipper's Creek, which it crosses near the mouth of Butcher's Gully, whence it traverses the ridge lying south of Old Man Creek, and then passes into the Upper Shotover near the junction of the Right Hand Branch, To accompany Bulletin Nº 7.



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Going southward from Skipper's Point, the Shotover fault follows the west side of the valley of that river until it reaches a point near Long Gully, where it crosses the Shotover, and, traversing the flank of the range, descends to Arthur's Point, whence it pursues a southerly course to Lake Wakatipu, the south arm of which lies along its track.

Moonlight Fault.—This is the great thrust-plane running parallel with the axis of the overturned fold, along which the wedge of Tertiary strata is deeply involved. It can be traced from Bob's Cove to the Upper Shotover. Its course is a little to the east of north, or almost exactly parallel to the Shotover fault. It has been fully described in connection with the involvement of the Tertiary conglomerates and sandstone, and calls for no comment here except to say that its significance as a structural feature of great importance was first noted by Mr. A. McKay.

Queenstown Fault.—This fault runs from the back of Queenstown along the steep ridge that leads up to Ben Lomond Saddle. Its course is clearly marked along the surface by a deep line of depression that can be traced quite clearly up the steep slope of the mountain when standing on the terrace behind Firth's. It is locally spoken of as a lode, but on examination it was found to be a simple fault-line, along which no mineralisation had taken place.

Kawarau Fault.—This fault crosses the Crown Range at the Cardrona Saddle, descending to the Kawarau Valley, which it follows to a point nearly opposite the Kawarau Falls, whence it crosses the crest of Peninsula Hill, locally known as the "Crag-and-Tail," and then descends to Lake Wakatipu.

From the crest of the Crag-and-Tail its course is marked by a ditch-like line of depression, the prolongation of which extends to Beach Bay, where the rocks are much faulted and broken.

The depression along the course of this fault is easily followed as it passes upward from the level of the lake to the crest of Peninsula Hill (Crag-and-Tail), being visible by the unaided eye even when many miles away. It is perhaps more easily distinguished from a distance than near-by, and is nowhere better seen than from the deck of a steamer standing out of Beach Bay on her way to Queenstown.

The ditch-like depressions that follow the courses of the Queenstown and Kawarau faults must be taken to indicate a comparatively recent date for the movements that formed them.

Queenstown and the region round about it are not infrequently the scene of earthquakes that are local rather than regional. The origin of these seismic disturbances has always been inexplicable, but may, after all, be traced to periodic slippings along these two faults, on which we have evidence of recent movement.

Flora.

The Wakefield and Macandrew mountains, and the Remarkables, lie on the edge of the great dry belt of Central Otago, and are destitute of trees or forest vegetation of any kind. The fringes of beech-forest on the shores of Lake Wakatipu, found creeping up the steep slopes of the Richardson and Eyre mountains, for the most part following watercourses and depressions, are all that now remain of the great forest that at one time covered the whole of the lower Wakatipu region. But, although forests are the exception rather than the rule, it must not be supposed that vegetation is scarce. From the level of the lake to the 2,000 ft. contour there is a well-defined zone, in which the hardy bracken (*Pteris aquilina*) grows so profusely and luxuriantly as practically to exclude all other forms of vegetation in its own domain, with the exception, perhaps, of the tutu (*Coriaria ruscifolia*), which seems to be able to resist all the efforts of the fern to choke and displace it.

Above the fern there is a zone covered with a great variety of subalpine shrubs, and above this there comes the typical tussock-land, reaching up to 6,500 ft. above the sea.

The bracken in its present abundance is a comparatively late arrival in the district, its present place having been formerly occupied by native shrubs and grasses. The rapid spread of the fern is the direct result of the persistent burning of the tussock, which, being unable to survive the successive fires that swept through it year by year, died out completely, its place being taken by the more vigorous bracken. The fern, however, is not without its uses, chief of which is the binding-power of its deep-reaching matted roots, whereby the soil on the mountain-slopes is prevented from being washed into the lake. It will doubtless continue in possession until the land is required for tree-planting or some other form of cultivation.

Most conspicuous in the zone above the fern is the graceful native heath (*Dracophyllum uniflorum*), and among the smaller plants the beautiful snowberry (*Gaultheria antipoda*) and the prickly little epacris (*E. pauciflora*), both of which grow in great profusion on the slopes of Perseverance Peak, around which the mountain-track to Ben Lomond gently winds.

The forest-trees are almost exclusively beech, among which *Fagus Solandri*, *F. cliffortioides*, *F. fusca*, and *F. Menziesii* are well represented. *Fagus Blairii* is occasionally seen near the lake-level, as also are two unusual forms that seem to lie between *F. Solandri* and *F. Blairii*. On the shore of the lake between Queenstown and Bob's Cove there are a few examples of what appear to be an aberrant form of *F. fusca*.

Among other trees are the totara (*Podocarpus totara*), kowhai (*Sophora tetraptera*), and titoki (*Alectryon excelsum*). The beautiful makomako, or wineberry (*Aristotelia racemosa*), the koromiko (*Veronica salicifolia*), the konini (*Fuchsia excorticata*), and tutu (*Coriaria ruscifolia*) are everywhere abundant in damp situations along the shores of Lake Wakatipu. The manuka, or tea-tree, (*Leptospermum scoparium*) grows plentifully on the dry gravel terraces between Queenstown and Bob's Cove, but is seldom seen far from the lake. The thorny Wild Irishman (*Discaria toumatou*), the " tumatukuru " of the South Island Maori, is fairly abundant everywhere at places between 1,000 ft. and 2,000 ft. Coprosmas and veronicas, in great variety, are present everywhere.

Among herbaceous plants are the white gentian (*Gentiana corymbifera*), very plentiful from 2,000 ft. to 3,500 ft., and numerous *Senecio*, *Celmisia*, and *Raoulia*. Of the latter, *R. Parkii*, first found at Mount Alta, in the Wanaka country, by Mr. Alexander McKay in 1880, is now very abundant at all heights between 1,000 ft. and 3,000 ft. In the past few years this patch-plant has spread down the Kawarau and Clutha valleys into the low country as far as Alexandra. In many places it has taken complete possession of extensive areas of river flat and terrace, a consequence resulting from the destruction of the native grasses by fire, aided perhaps by the spoliation caused by the rabbit.

I am indebted to Mr. William Wilcox, gardener in charge of the Queenstown Domain, for the following list of *Olearia* and *Senecio* growing in the Domain : Olearia angustifolia (Hooker),* O. avicenniæfolia (Hooker), O. Colensoi (Hooker), O. Forsteri (Hooker),* O. furfuracea (Hooker), O. Haasti (Hooker), O. insignis (Hooker),* O. macrodonta (Baker), O. moschata (Hooker), O. nitida (Hooker), O. nummularifolia (Hooker),* O. oleifolia (Kirk), O. Traillii (Kirk),* O. Traversii (Hooker),* O. virgata (Hooker); Senecio Bidwillii (Hooker), S. Buchanani (Armstrong),* S. Grezii (Hooker),* S. Huntii (F. Muell.),* S. Hectori (Buchanan),* S. elæagnifolius (Hooker),* S. laxifolius (Buchanan),* S. Monroi (Hooker), S. revolutus (Kirk).

Climate.

Reference has already been made in the opening paragraphs of the first chapter to the scenic attractions and salubrious climate of Queenstown and surrounding region. It would be difficult to find words of sufficient praise for the climate, which is unsurpassed by that of any

* Introduced from other parts of New Zealand.

other part of New Zealand—a country justly famous for its equable temperature, floods of sunshine, refreshing showers, and verdure of vegetation all through the year.

The climate of the district around the shores of Golden Bay, in Nelson, perhaps compares more nearly than that of any other part of the Dominion with the climate of Lake Wakatipu. It is sunny and dry both in summer and winter, but lacks the bracing and invigorating whiff of the clear mountain air for which Queenstown is celebrated.

In the Wakatipu district there is no clay subsoil—a matter of no little importance in determining the healthfulness of a place utilised for settlement. The rocky tumbled moraines, gravel terraces, and old lake-strands at all times insure the most perfect underground drainage for the rainfall.

According to Mr. Richmond Keele, the average number of days of sunshine per year, calculated from the returns of the past three years, amounted to 268 days upon which the sun shone wholly or partly either at 9 a.m. or 2 p.m., when the daily record was taken.

I am indebted to Captain R. A. Edwin, R.N., Director of the Government Meteorological Office, Wellington, for the following particulars relating to the recorded rainfall at Queenstown :—

The rainfall-record for that place, which extends from 1871 to 1880, and from 1890 to the present time, shows that the mean annual rainfall is 31·17 in., and that the driest month of the year is August, and the wettest October. The winter, summer, and autumn are dry, the greatest rainfall coming in spring, when it is most needed.

The lowest recorded rainfall for twelve months was 22·42 in. in 1879 ; and the greatest, 60·08 in. in 1878. It will be noted that the wettest year on record was followed by the driest.

Table of Heights.

During the progress of the work, barometric heights were obtained of passes or saddles, junctions of streams, lakes, and many points of geological and topographical interest. All the readings were taken twice, and most of them checked by a reference to a trigonometrical point.

	Ft.
Arrowtown, at junction of Bush Creek	1,175
Soho and Arrow junction	1,525
Coronet Creek and Arrow junction	1,660
Macetown junction	2,000
Scanlon's Creek junction	2,060
Bush Creek junction	2,400
Forks of Bush Creek	2,750
Sawyer's Creek junction	2,930
Skipper's Point	1,800
Platform of Skipper's Bridge	1,605
Shotover, below Skipper's Bridge	1,400
Bullendale	2,175
Junction of Skipper's branches	1,950
Roaring Meg junction	1,980
Junction of Stony Creek	1,395
Pleasant Terrace	1,800
Yates Terrace, Stony Creek	1,850
Left Hand Branch, Shotover	2,230
Arthur's Point Pass to Shotover	1,350
Mouth of Moke Creek	1,420

	Ft.
Ben Lomond Saddle	4,150
Top of Resolution Peak	3,750
Lake Kilpatrick	1,790
Moke Lake	1,710
Moke Creek Post-office	1,830
Junction of Maconnachie's and Moke creeks	1,500
Low level on copper lode from Moke Creek	1,560
Lake Dispute Saddle	1,830
Lake Dispute	1,525
Moke Lake Saddle from Five-mile Creek	1,990
Lake Johnson	1,285
Mouth of Shotover	1,000
Shotover Terrace, on main road	1,185
Signal Hill	1,480
Von Terrace	1,165
Saddle on Richardson Range, on track to Lake Luna	4,400
Saddle between Twenty-five-mile Creek and Lake Luna	2,690
Lake Luna	2,625

CHAPTER III.

GLACIATION.

Extent and Character of Glaciation.

The features of the land in the Lake Wakatipu region, and from there southwards to the plains of Southland and eastward to the sea, up to a height of 6,500 ft. above sea-level, are everywhere dominated by evidences of ice-erosion on a scale of magnificence that is unknown elsewhere in the Southern Hemisphere, and is perhaps without a parallel outside the polar regions.

The existing valley-glaciers of New Zealand rank among the largest on the globe; but they are as shrivelled pigmies compared with the majestic sheet of moving ice that in the glacial period covered all but the highest peaks, and drove its furrowing coulters deeply into the sides of the resisting mountains.

Each valley and depression contained its own glacier, but all were united in one, forming part of the great continental ice-sheet that covered the land. During the period of greatest refrigeration the ice-sheet attained a maximum thickness probably exceeding 7,400 ft. Its surface formed a vast plateau, through which only the tops of the highest peaks appeared, looking like lonely islets in a frozen sea.

A striking feature of this gigantic glaciation is the remarkable freshness of the ice-grooved surfaces, the beautiful flowing contours being everywhere sharply outlined in their carpet of native grasses.

Hitherto it has been the practice of New Zealand geologists to speak of a great extension of the present day valley-glaciers, but to deny the existence of a glacial period similar to that of the Northern Hemisphere. This view was attended with many difficulties. It ignored the fine ice-shorn rock-benches on the slopes of Ben More Range in Central South Canterbury, and the existence of the sheet of glacial silts and boulder-clay covering a wide stretch around Timaru and Dunedin. It attempted to find some explanation for the existence of the Henley Boulder-clay that did not involve a glacial period, and failed to recognise the remarkable evidences of glaciation presented on all hands in the Wakatipu region.

Hutton was always opposed to a Pleistocene glacial period in New Zealand. He thought it doubtful whether kames, drumlins, true erratics, or stratified till deposits existed in the country; and contended that the Ice Age in New Zealand consisted only of a great extension of the valley-glaciers of the South Island. There was no evidence, he said, of the former existence of an ice-sheet, or of any floe ice or icebergs in the New Zealand seas, and no proof that any of the glaciers, even in the period of their greatest extension, reached the sea.*

Sir Julius Von Haast,† as the result of an intimate knowledge of the alpine regions of Canterbury and Westland, believed that by far the greater portion of our Southern Alps was covered with perpetual snow during what he called "The New Zealand Glacier Period." He also contended, in opposition to Hutton, that the West Coast glaciers extended some distance into the sea.

In the Wakatipu region, along the floor of the valleys, there are to be found eskars, rock-basins forming lakes and tarns, *roches moutonnées*, ice-grooved and striated hummocks, true erratics, perched blocks, morainic matter, and till; on the foothills, broad ice-cut platforms or benches; and on the slopes of the mountain-ranges, tier upon tier of ice-cut benches and innumerable mammillated hummocks.

In the direction of flow of the Kawarau branch of the Wakatipu glacier, erratics from a few pounds in weight up to hundreds of tons occur in countless numbers, scattered over the valleys and foothills from the level of the lake up to a height of 4,000 ft. above the sea, or 3,000 ft. above the lake. In certain localities scores of these foreign ice-borne stones are grooved and striated. Large angular masses of the fossiliferous Tertiary sandstone are found on the flanks of Perseverance Peak and Bowen Peak, at heights ranging from 1,950 ft. to 3,000 ft., having been torn from their place at Bob's Cove, some 1,000 ft. or 1,300 ft. above the sea, and carried onward and upward by the advancing ice.

Rock Hummocks, or Roches Moutonnées.

These occupy a great part of what is known as the Arrow Flat, which is merely a glacier-basin or *cirque*, bounded on three sides by the Kawarau, Shotover, and Arrow rivers, and on the remaining side—that is, on the west—by the Coronet Range—itself merely the southern termination of the Richardson Mountains. (See Plate XIV.) The even, ice-shorn, grass-covered slopes of the Coronet Range, as seen from Arrowtown, sweep around the west side of the Arrow Cirque in a great crescent, like the auditorium of a gigantic amphitheatre.

The *roches moutonnées* occur in narrow, more or less continuous, ridges that trend from Arrowtown to the Kawarau—that is, they follow in a general way the strike of the mica-schist, which is about north-west–south east. They are commonly rounded in outline and whale-backed in longitudinal elevation. In some places they are so worn down as to be almost obliterated, in other places they attain a height of 30 ft. or 40 ft. In the area lying between Lake Hayes and Arrowtown the space between the successive rock hummocks and ice-planed ridges is filled with fluvio-glacial drift, which is sometimes so deep as to all but cover the underlying hummocks.

East of Hogan's Road, near the junction of that road and the Arrowtown–Cromwell Road, the hummocks are often separated by undrained hollows that become tarns in the winter and spring.

The general trend of these ice-worn ridges lies at right angles to the flow of the glacier-ice, as determined by the direction of the striæ on the rock-surfaces found at Arrowtown and elsewhere.

Glacial Till.

The floor of the Arrow Flat and the gently undulating slopes of all the ice-shorn ridges lying in the bottom of the Arrow Cirque, between the Shotover and Arrow rivers and between the foot of the Crown Range and Kawarau, are covered with a sheet of greyish-coloured stony

* Captain F. W. Hutton. "Glacial Action in New Zealand," pamphlet, Aust. Assoc. Adv. Science, p. 6; and "Geology of Otago," Dunedin, 1875, p. 80.

† Haast. "Geology of Canterbury and Westland," Christchurch, 1879, p. 379.

PLATE XIII.

Whale-back Mica-schist Ridges and Glacial Eskars near Arrowtown, with Large Erratic in Foreground and Crown Terrace in Distance.

Photo James Park.]

[*To face p. 26.*

PLATE XIV.

BOTTOM OF ARROW CIRQUE, SHOWING ICE-WORN ROCK-HUMMOCKS.

Photo lent by Tourist Dept.]

Arrow Eskar in Middle Distance.

Photo James Park.]

Stony Boulder-clay, Arrowtown.

Photo James Park.]

glacial till, consisting of a confused deposit of excessively fine glacier sand and clay mingled with a sprinkling of rounded gravel and angular and semi-angular fragments of quartz and mica-schist. The finer material consists mainly of quartz and quartzose mica-schist; the coarser mainly of greywacke, and the red and green breccia-tuffs commonly associated with that rock. The quartzose material is of local origin, while the greywacke and its associates are foreign to the district, being ice-borne from the mountains lying between Lake Te Anau and Lake Wakatipu. In a few places the till is rudely stratified. It is extremely fertile, and for that reason is highly cultivated.

The till also covers the surface of the Crown Terrace, and is found on the slopes and summit of Queenstown Hill, up to a height of 3,000 ft. above the sea, or 2,000 ft. above the surface of Lake Wakatipu. A thin sprinkling of greywacke gravel, and occasionally red clay, is also found on the slopes of Perseverance Peak, on the track to Ben Lomond, up to a height of 3,000 ft. above the lake.

In general terms it may be said that this till is found everywhere, over hill and dale, in the wake of the Kawarau branch of the great Wakatipu glacier.

It should be noted that among the foreign material in the till there is always a small percentage of granite, norite, diorite, and other crystalline igneous rocks. In a few places these rocks occur more plentifully than in others, and in this respect the lower slopes of Queenstown Hill, facing Frankton Arm, and the vicinity of Lake Johnson are specially favoured localities.

The crystalline rocks occur in small pebbles and in well-rounded boulders up to 2 ft. in diameter.

A few erratic boulders of greywacke and greenstone breccia of large size lie imbedded in the till on the Arrow Flat and Crown Terrace.

Origin of Glacial Till.

The till varies considerably in composition in different places. In one place fine-bedded silts predominate; in another, clays, silts, sands, grits, and angular fragments of quartz and schist of all shapes and sizes are intermingled in a confused mass or perhaps rudely stratified, while in other places the material is mainly fluvio-glacial drift, in which well-rounded foreign rocks are conspicuous. Along the margin of the Arrow Cirque the till consists mostly of small angular pieces of schist, always quite fresh and undecomposed, and closely resembling the small screenings of broken rock often used in the making of concrete-work. But one class of material is found to pass into another sort with a suddenness that sometimes causes much perplexity and astonishment.

The origin of the till does not appear to be due to the operation of one cause, but rather to two or more causes or agencies operating at the same time. In one place we have silts and rock-flour that were manifestly laid down in still water, in another the boulder-clay of a ground-moraine, and in another gravels and drifts that are purely fluvio-glacial.

The water-worn drifts were obviously formed by subglacial streams that drained the ice-sheet at different points, uniting, and branching, and uniting again. The boulder-clays appear to have been infra-glacial material spread out in the wake of the retreating ice-sheet; while the finely bedded silts, with paper-like laminæ, consist of rock-meal and rock-flour that settled slowly in tarns or lagoons. Gold-bearing slimes that are allowed to settle slowly in the settling-tanks used in connection with the cyanide treatment of gold and silver ores always exhibit a finely laminated structure; and in tarns with a gentle overflow the silts would doubtless settle in the same manner. At certain points the different sorts of glacial material meet and intermingle.

The till found spread over Queenstown Hill and adjacent ridges, up to 3,000 ft. and more above the surface of Lake Wakatipu, is very largely fluvio-glacial drift, and must have been infra-glacial material, entangled in or near the under-surface of the ice, and carried upward as the advancing sheet surmounted the ridges it encountered in its path. The masses of fossiliferous marine sandstone plucked from the Lower Tertiary rocks at Bob's Cove, and carried to a height of 3,000 ft. on the slopes of Bowen Peak, prove conclusively that the Wakatipu glacier flowed upward and over the obstacles it could not remove.

The proportion of foreign material in the till varies in different places. In the fluvio-glacial drifts on Queenstown Hill probably 60 per cent. of the pebbles and boulders are greywacke and greenstone breccia derived from the west side of the mountains drained by the Greenstone River on the west side of Lake Wakatipu ; while near Arrowtown the material is mainly of local origin, only a thin sprinkling of greywacke being present.

Along the western slope of Queenstown Hill, facing Frankton Arm, as far north as Lake Johnson, there is a zone in which, besides greywacke, boulders of granite, norite, and diorite are comparatively common—more common than in any other part of the district. These crystalline rocks are not known *in situ* nearer than the divide between the head of the Eglinton River and the upper end of Lake Te Anau, which means that they have been carried some forty miles from a distant watershed lying on the west side of Lake Wakatipu, and are therefore more travelled than the greywackes which have been transported from the watershed of the Greenstone River.

The greater abundance of crystalline rocks between Frankton Arm and Lake Johnson would indicate that this area lay in the track of that portion of the ice-stream which flowed from the country at the head of the Eglinton River.

Erratics.

These are very numerous along the shores of Lake Wakatipu from the Twenty-five-mile Creek to Queenstown, and from there to lower Shotover and Arrow Flat. They form the bulk of the material in the fluvio-glacial drifts lying between Bob's Cove and the head of Frankton Arm, and of the material composing the Queenstown moraine.

In the drifts they occur mostly as small boulders, commonly well rounded and generally under 2 ft. in diameter, although rounded boulders up to 4 ft. and even 6 ft. in diameter are not rare.

The distribution of the erratics affords a trustworthy guide as to the direction of flow of the Wakatipu glacier and of the subsidiary streams of ice that pushed their way to the north and east towards Moke Creek and Shotover.

The great bulk of the erratics is composed of greywacke ; and after that rock, in the order of their abundance, come the green and red tuffs and breccias so commonly associated with the greywacke. After the greenstone breccias come norites, diorites, and granites.

The large angular fragments of rock so conspicuous in the Queenstown moraine are mainly greywacke and greenstone tuff, ranging from a foot in diameter up to the size of a shepherd's hut, the larger masses weighing between 200 and 300 tons. Many of the erratics at Bob's Cove and near Lake Johnson are beautifully ice-grooved and striated. (See Plate XVII.)

Of the thousands and tens of thousands of erratics scattered about the Wakatipu region, perhaps none are more interesting than one lying in Scanlon's Gully about a mile above Macetown, and another in Stevenson's Sluicing Claim at Skipper's Point.

The Macetown Erratic.—The erratic in Scanlon's Gully is a rounded boulder of hypersthene-gabbro about 2 ft. in diameter. It lies in the bed of the stream a few chains from the Goldburn. Scanlon's Gully is a narrow V-shaped valley, some three miles long, bounded by grass-covered ridges from 3,000 ft. to 5,500 ft. high. A careful search was made of the floor of the valley and of the surrounding slopes and ridges for other erratics, but without result.

The erratic would appear to be the only foreign boulder in the watershed of the Arrow River above the junction of the Soho. At any rate, a careful traverse and examination of the bed of the Arrow from Macetown to its source, and of all the small tributaries flowing into it, failed to disclose another erratic or foreign boulder of any kind whatever.

The Arrow watershed is surrounded by mountains rising from 5,000 ft. to 6,000 ft. high. By some strange happening this solitary boulder became separated from its associates and transported by the ice-sheet northward across the peaks of the Richardson and Macandrew mountains, while its fellows were slowly borne eastward towards Queenstown.

Skipper's Point Erratic.—This was a small rounded boulder of granite, some 8 in. in diameter, found by Mr. Miles Aspinall and the author on the floor of Stevenson's Sluicing Claim at Skipper's Point. A diligent and protracted search in the bed of Skipper's Creek, and among the heaps of boulders piled up in the old sluicing-claims on the west bank of the Shotover, between Skipper's Point and Stony Creek, failed to discover another erratic of any description whatever. It seems improbable that this boulder can be the only ice-borne erratic in so extensive a watershed as that of the Shotover, but others are so rare, if they exist at all, that they are not easily found. No outcrop or occurrence of any granitic or other crystalline rock is known in the Shotover watershed, while the narrow band of marine Tertiaries deeply involved in the Moonlight shear-plane contains only fragments of schist and quartz. There is no reason to doubt the true erratic character of the boulder.

Skipper's Point erratic was found among the terrace-gravels lying on the old glacial channel of the Shotover immediately below Skipper's Creek junction ; but what stream carried it to its place of discovery is impossible to say. The Macetown erratic, as we have seen, was found near the mouth of a deep narrow gully, and must have been dropped or stranded not far from its present place. That much is certain, but in respect to the Skipper's Point erratic we have no such assurance.

Skipper's Creek reaches back to Mount Aurum, a distance of fifteen miles, and the Shotover rises at Lake Lochnagar, at the north end of the Richardson Mountains, distant some twenty five miles. It is just posssible—but this is only a surmise—that both the Macetown and Skipper's erratics were transported from the crystalline *massif* near Milford Sound by that portion of the continental ice-sheet which passed over that region. In what way these fugitive boulders became separated from their fellows must remain a matter of mere conjecture.

The Shotover watershed is encircled by mountain-chains varying from 6,000 ft. to 8,000 ft. high, unbroken anywhere by low passes. It is obvious that the Skipper's and Macetown erratics must have been transported by ice that rode over the crest of the Richardson Mountains, thus adding one more circumstance to the chain of evidence bearing on the former existence of a continental ice-sheet covering the South Island of New Zealand in the Pleistocene period.

Perched Blocks.

These are ice-borne erratics that have been stranded in prominent positions.

A very fine example of a perched block, and the first described in New Zealand, is found resting on the crest of a low but somewhat steep ice-worn ridge on the Kawarau side of Hogan's Road, that leads from the upper end of Lake Hayes to the Arrow Bridge on the Cromwell Road. It is situated about half a mile from the junction of Hogan's Road and Arrow South Road, running behind the Hospital, and can be seen from many points within a radius of a mile. (See Plate XVI.)

This great erratic of greywacke measures some 24 ft. by 12 ft. by 10 ft., and weighs about 230 tons. It rests directly on the ice-worn surface of the mica-schist. Its lower surface is grooved, polished, and covered with fine striæ, that run in the same direction from one end of the boulder to the other. The striæ are remarkably well preserved. The polished and striated surface covers an area of over 400 square feet. (See Plate XVI.)

About 15 chains west of the perched erratic just described there is another erratic of greywacke lying in a hollow. Its dimensions are 20 ft. by 14 ft. by 10 ft., and its weight about 240 tons.

Another large erratic of greywacke lies stranded on the floor of the old sluicing-claim on the Arrowtown end of the Crown Terrace, near the base of Mount Beetham. It weighs about 80 tons, and is situated some 700 ft. higher than Hogan's Road erratics.

Moraines.

There are three well-defined moraines in the area examined during the past summer—namely, the Queenstown moraine, Mount Nicholas or Von moraine, and Miller's Flat moraine. Of these the Mount Nicholas moraine is by far the greatest. It extends from Beach Bay to the Von River, a distance of eight miles, and forms the foothills lying between Walter Peak and Lake Wakatipu. It is a lateral moraine, resting on an ice-eroded core of mica-schist and schistose greywacke. It consists mainly of tumbled fragments of mica-schist and greywacke, some of them of enormous size, mingled with fluvio-glacial drifts that are composed mainly of greywacke and quartzose material. Its thickness exceeds 300 ft.

The Queenstown moraine lies against the foot of Queenstown Hill, facing Lake Wakatipu, and, although of small extent, is well known from the circumstance that the greater part of Queenstown is built on it, while the beautiful Domain of that picturesque town is situated on the tongue of land it forms projecting into the lake between Frankton Arm and Queenstown Bay. (See Frontispiece.) It is a lateral moraine, composed chiefly of fluvio-glacial drifts of sand and gravel, with which are mingled numerous angular fragments of rock, ranging from small pieces up to masses weighing over 200 tons. The bulk of the boulders in the fluvio-glacial drift is greywacke, while the angular masses are mainly composed of the same rock. The prevailing greywacke is a fine-grained grey rock, but it is found in endless variety of colour and texture—namely, green, red, purple, and speckled ; gritty and brecciated.

Miller's Flat moraine extends along the foot of the Coronet Range, from the point where the coach-road begins to ascend to the Coronet (Skipper's) Saddle to a point half a mile from Arrowtown. It is a lateral moraine, mainly composed of mica-schist. At the Arrow end it forms low hummocky ridges, but near Millar's Flat it appears as a flat-topped terrace, the material having been planed down to an even surface by the Shotover glacier.

Queenstown Eskar.

The foothills of Queenstown Hill, lying between Arthur's Point Road and the Frankton Arm of Lake Wakatipu, are composed of fluvio-glacial drifts arranged in the form of hummocky ridges and eskars that lie immediately above and behind the terrace, at the 150 ft. level, on which the convent is built. Starting a little beyond the stone bridge in the street leading up from the wharf, the ground rises somewhat abruptly on to the topmost of the ancient lake-strands which forms the narrow terrace spoken of above.

Behind the terrace, and nearly in a line with the street, there are two short hummocks, while a third and larger kame or eskar runs along the back of the terrace for some distance towards Frankton Arm. This eskar varies from 60 ft. to 100 ft. high, and is mainly composed of rudely bedded sands and gravels, commonly a yellowish rusty-brown colour. It is cut through in a few places by small lateral streams, and is there seen to be overlain by a coarse boulder-clay or drift, mainly composed of sand, clay, and greywacke boulders. It is probably this covering of coarse drift that has preserved it from destruction.

Portion of Striated Surface of Perched Erratic of Greywacke, near Hogan's Road, Arrow Flat.

Photo C. A. Cotton.]

Perched Erratic of Greywacke, near Hogan's Road, Arrow Flat.

Photo James Park.]

Ice-striated Boulder of Greywacke, Bob's Cove, Lake Wakatipu.
Photo James Park.]

Ice-striated Erratic of Greywacke, Bob's Cove, Lake Wakatipu.
Photo James Park.]

PLATE XVIII.

LARGE ERRATIC BOULDER OF GREYWACKE IN QUEENSTOWN DOMAIN.

Arrow Flat, showing Ice-planed Rock-hummocks.

Photo James Park.]

Queenstown Eskar, taken behind Convent

Photo James Park.]

PLATE XX.

Stony Creek Waterfall, at Crossing of Involved Tertiaries
Photo Miles Aspinall.]

This eskar lies nearly at right angles to the path of the glacier-flow, and the comparatively uniform size and bedded character of the material render it difficult to understand the conditions in which it was deposited. Its shape and material would, however, lend colour to the belief that it was laid down in an ice-tunnel drained by a stream running parallel with the flank of Queenstown Hill.

Whatever the true explanation of its formation, it is interesting to note that in outline and structure the Queenstown eskar is not dissimilar to those found in Scotland. Its resemblance to the kames around Highlaw, a mile or two south of Cruden Bay, near Slain's Castle, on the coast of Aberdeenshire, is very noticeable.

The Wakatipu Glacier.

Wakatipu Valley was the meeting-place of giants. The Dart and Rees glaciers, carrying a load of schistose material, united at the south end of Mount Alfred and crept down the valley till joined by the great Greenstone and Von glaciers that descended from the Livingstone Mountains and the region lying to the north of Lake Te Anau.

The Von glacier, with one leg in the Afton Burn and the other leg in the Von, strode over the summit of Mount Nicholas, which it planed down into the beautiful dome we now see surmounting that mountain.

The pressure of the Von glacier, when added to that exerted by the Greenstone glacier, forced the stream of ice coming from the head of the lake against the Richardson Mountains. The course followed by the Greenstone and Von glaciers can easily be traced by the distribution of the distinctive load of greywacke material which they carried. After merging into the Upper Wakatipu stream the united glaciers descended to Queenstown, where the ice-stream divided, one branch continuing down the valley to Kingston, while the other and perhaps greater branch flowed down the Kawarau Valley. The pressure from the south-west exerted by the Greenstone and Von glaciers caused small lateral streams of ice to flow northward through the low passes in the Richardson Range into the Shotover watershed.

The distribution of the greywacke erratics informs us that a small glacier flowed from the main glacier up the Twenty-five-mile Creek nearly to Lake Luna, causing a diversion of the Ben More glacier into the head of Moonlight Valley.

Two lateral streams of ice ploughed their way through narrow passes into the Moke Creek drainage-area, uniting at the end of Moke Lake, which they excavated in their northward course.

At Queenstown another lateral stream of ice flowed through the gap between Bowen Peak and Ben Lomond, uniting with Shotover glacier at Arthur's Point.

It is obvious that at this time the Wakatipu, Shotover, Arrow, Kawarau, and other glaciers did not exist as separate valley-glaciers, but were merely the serrated underportion of the great ice-plateau of which they formed the shearing and excavating tools.

Ice-terraced Mountain-slopes.

Lake Luna Ice-benches.—Finely preserved examples of these benches are exposed on the west side of Ben More, rising from the shore of Lake Luna to the summit of the range, where they stand out in fine relief in their carpet of yellow tussock. (See Plate XII.)

Thirty or more benches or shelves can be distinguished when standing on the west side of Lake Luna, the uppermost being as sharply defined as the lowest. They are horizontal or gently undulating, and many have an undrained hollow behind them. They vary from a few yards to 50 yards wide, and from 30 ft. to 70 ft. high, although some are lower and others higher than these limits. The lower terraces are the highest and widest. The rock in which they are excavated is a moderately hard quartzose mica-schist.

It is noticeable that all the rock-benches contour round the inequalities of the slope on which they are impressed. The mechanics of their excavation is difficult to understand; but it is almost certain that all were carved out at the same time, for it is impossible to conceive that each shelf can represent a separate epoch of advance and recession of the ice-sheet during the period of glaciation.

These beautifully preserved rock-shelves present as fine an example of ice-erosion, or, more properly, ice-shearing, as there is recorded in the literature of geology. They are probably unique, and are certain to be of much interest to glacialists in all parts of the globe.

Mammillated Slopes of Coronet Range. — The crescent-shaped tussock-covered slopes of this range fronting the Arrow Cirque, almost from the level of Millar's Flat to the saddle on the road leading over the range to Skipper's Point, are terraced with long lines of ice-formed benches, many of which have undrained hollows behind them. On approaching the saddle, the continuous benches and low horizontal ridges are replaced by rounded knobs that impart a beautifully mammillated appearance to the higher slopes of the range. The country rock is a weak, rather friable mica-schist, and in almost all the hummocks and benches examined it was found to be broken and shattered, and, where not shattered, always much bent and crumpled by the weight of the ice-sheet.

Glaciated Remarkables.—The benches on the slopes of the Remarkable Mountains near Kingston, although not so distinct and continuous as those at Lake Luna, are nevertheless notable examples of ice-erosion. They extend from the level of the lake to the summit of the range, which in the glaciated portion reaches a height somewhat exceeding 6,500 ft. above the sea.

Ice-benching on Concave Slopes.—It is noticeable that the benches and ice-terraces are in all cases most strongly impressed on the concave side of the faces against which the ice-floe was directed in its downward course towards the lowlands. The inner or convex side is commonly worn into smooth, even, billowy slopes. It is not certain whether this can be applied as a broad generalisation in all glaciated lands, but it is a point that should not be lost sight of in future investigations.

Ice-cut Platforms.

The best example of a broad ice-cut rock-platform is what is known as the Crown Terrace, which extends along the foot of the Crown Range from Arrowtown past Mount Beetham to the Kawarau Gorge, a distance of some six miles in an unbroken stretch. It varies from half a mile to two miles wide, and is covered with a thin mantle of glacial till, of which the pebbles and boulders are mainly greywacke. In a few places on the Arrow face of the terrace there is a layer of schistose glacial drift, consisting chiefly of large fragments of micaceous quartz-schist, chlorite-schist, and quartz, with only a small percentage of water-worn greywacke gravel. In this drift, which has the appearance of a ground-moraine or a moraine that has been overrun by ice, there are a few very large masses of greywacke, one of which weighs about 80 tons.

The Crown Terrace is excavated in the solid rock, and lies from 600 ft. to 700 ft. above the Arrow Flat—that is to say, it lies at the same level as the floor of the old Arrow glacial valley, and is merely the eastern continuation of that old floor, having been excavated by the Arrow glacier, one branch of which entered the great Arrow Cirque at Arrowtown, while the other passed round the back of Mount Beetham, and thence crept eastward along the foot of the Crown Range, against which it was pressed by the united Shotover and Kawarau glaciers.

The floor of the Arrow glacial valley stood some 700 ft. above the floor of the Arrow Cirque, relatively to which it was a hanging-valley. The Arrow glacier, on meeting the great glacier occupying the Arrow basin, was deflected sharply to the east, and, following the general direction of flow of the ice-sheet, ploughed its path along the base of the Crown Range, its work resembling that of a coal-cutting shearing-machine making a horizontal cut. The

Pig Island, Lake Wakatipu, ice-shorn into Flat Platform.

Photo James Park.]

Ice-worn and Striated Rock-surface, Bob's Cove.

Photo James Park.]

face of the Crown Terrace fronting the Arrow River shows traces of horizontal grooves and benches that were probably excavated by the ice-sheet that forced the Arrow glacier against the Crown Range.

It has been mentioned elsewhere that the slopes of the Crown Range behind Mount Beetham still show the remains of an ascending succession of narrow rock-benches that are fairly well preserved in places. These were doubtless the work of the Arrow glacier.

A diagrammatic section from the Crown Range across the Crown Terrace to the Arrow Flat is shown in Fig. 7 below.

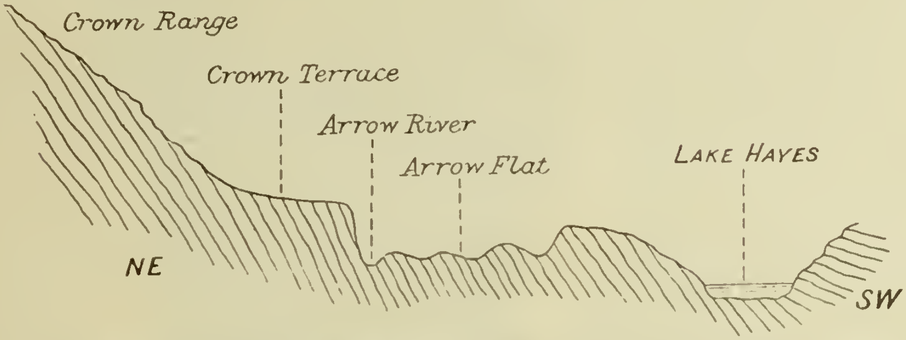

Fig. 7. Diagram showing Crown Terrace Rock-platform, Arrow Flat, and Lake Hayes Basin. The rock is a soft friable mica-schist, belonging to the Maniototo Series.

Pig Island, in the upper reach of Lake Wakatipu, has been ice-planed down to a flat platform only a few feet above the surface of the water. If the lake were drained dry this island would present the appearance of a table-topped ridge. The low relief to which it has been reduced by ice-erosion is well shown in Plate XXI.

Striated Surfaces, and Direction of Striæ.

On an outcrop of quartzose mica-schist in the paddock lying in front of the Presbyterian Church at Arrowtown the striæ have a bearing of 26°. measured from the true meridian—that is, the path of the glacier occupying the Arrow Cirque was from Lake Hayes north-eastward towards Arrowtown, and the evidence of the striæ coincides with that of the distribution of the erratic ice-borne greywacke drift. In considering the direction of flow of glacier-ice in a confined basin or cirque like that of the Arrow Flat, which was the meeting-place of the Kawarau, Shotover, and Arrow glaciers, we must always bear in mind that, while the general trend of the ice-sheet was eastward—that is, from the high lands, where it had its source, towards the sea—there would be portions of the ice that would follow devious ways, according to the contour of the obstructions met with, in the way that protruding ledges and depressions in the bed of a stream are known to cause the formation of cross-currents, eddies, and swirling water-pools.

The longer axis of the great perched erratic near Hogan's Road runs nearly east and west, and the direction of the striæ is parallel to this axis. Hence we may safely conclude that, if the erratic occupied the same position when locked in the floor of the ice-sheet that dragged it along as it now does as it rests on the narrow ridge on which it is perched, the flow of the ice was approximately east and west. The erratic is greywacke, transported from the Humboldt or Livingstone Mountains across Lake Wakatipu to the Arrow Flat. The path of the ice that carried it must have been from west to east—that is, parallel to the main axis of the erratic and its engraved striæ.

In a narrow gulch sluiced out of the terrace fronting the lake near Bob's Cove there is a large rounded boss of quartzose mica-schist that is finely striated over an area of 800 square feet. This ice-planed and striated outcrop is situated some 15 chains from Mr. Burrough's hut, and 10 chains back from the beach. (See point marked A on Plate XXVIII.) When following up the gulch, the outcrop is found standing up as a high bold face on the right or east side. The preservation of the striæ was due to the covering of alluvium, which protected the surface of the rock from weathering.

This is the largest and finest striated rock-surface known in New Zealand, and there is good reason for the belief that further sluicing would uncover a much greater striated surface than that now exposed. Striated boulders and pebbles lie scattered around the ice-worn outcrop in great profusion.

The general trend of the ice-striæ here is from south to north, the ice-grooving being in all probability the work of the lateral ice-stream that left the main Wakatipu glacier at this place and flowed northward through Lake Dispute Valley and across the low pass to Moke Lake.

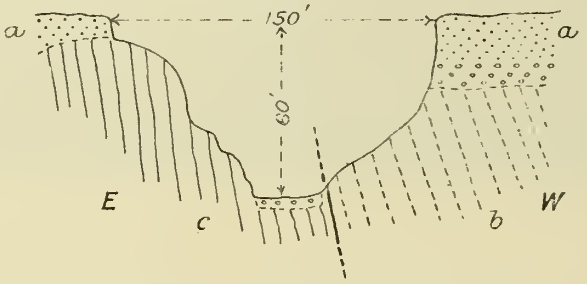

Fig. 8. Section showing Ice-striated Rock-surface near Bob's Cove. Looking down Gulch towards Lake Wakatipu.

a. Alluvial drift. *b.* Marly clays of Tertiary Series. *c.* Quartzose mica-schist of Kakanui Series.

Slope and Crag.

The peculiar configuration of the isolated ridges and hills lying between Lake Wakatipu and Arrow River affords unrivalled evidence of the intense abrasion to which obstacles in the path of the great ice-sheet were subjected during the glacial period. These ridges commonly present a long, smooth, gradually ascending slope on the side that faced the ice-flow, while the opposite side, protected from abrasion, is steep and rough. The long, smooth, glaciated slope is what is known as the *stoss-seite*, and the steep craggy side as the *lee-seite*. In nearly all cases the long slope has fine flowing contours, and is commonly covered with a thin mantle of boulder-clay.

Queenstown Hill; Fortification or Ferry Hill, situated between Lake Johnson and the Shotover; Cave Hill, also called Slope Hill, lying between the Shotover and Lake Hayes; and Morven Hill, immediately east of Lake Hayes, all exhibit this feature in a very marked degree, Slope Hill and Ferry Hill, as seen from Arrowtown Road, being perhaps the best examples.

The glaciated hill lying on the south side of Frankton Arm, named the "Crag-and-Tail," is a typical example of the slope-and-crag phenomenon of ice-erosion. Its beautiful ascending ice-smoothed slope and steep crag can be well seen from the Frankton Road at any point half-way between Queenstown and Frankton Flat. (See Plate XXII.)

At the foot of the long slope, or *stoss-seite*, there is commonly a hollow or basin. Thus, at the foot of the Crag-and-Tail we have Lake Wakatipu; at the foot of Queenstown Hill,

PLATE XXII.

South End of Lake Hayes, showing Ice-shorn Hills beyond.

Photo lent by Tourist Dept.]

the arm of that name ; at the foot of Ferry Hill, Lake Johnson ; at the foot of Slope Hill, the Shotover Valley ; and at the foot of Morven Hill, Lake Hayes.

The islands in Lake Wakatipu during the period of glaciation penetrated the bottom of the Wakatipu glacier like the *platten* of the modern Swiss glaciers, and were on this account subjected to intense erosion. They also exhibit the slope-and-crag feature, which is always characteristic of extreme glaciation. The islands in Lake Wanaka, as well as Mount Iron at the south end of that lake, also present the same configuration.

Thickness of Ice-sheet.

The marks of ice-abrasion, in the form of mammillated and terraced slopes, are seen on the Remarkables from the surface of Lake Wakatipu up to a height of over 6,500 ft., and on the Eyre and Richardson mountains up to 6,000 ft. The dome-shaped crests and terraced slopes of the Crown, Wakefield, Macandrew, and Coronet ranges tell us that even the highest peaks were overridden by a continuous ice-sheeet of continental dimensions. But how far the surface of this ice-plateau stood above the 6,500 ft. contour is a matter of almost mere conjecture, in the present state of our knowledge with regard to the digging and abrasive power of glacier-ice.

In the Arrow Cirque there stood a thickness of ice that we know exceeded 5,000 ft., a mass capable of exerting a compressive stress exceeding the ultimate crushing-strength of the weak mica-schist in that area. In such a case we have no difficulty in understanding the genesis of the mammillated floor over which the ice slowly moved in its seaward course.

What we cannot satisfactorily determine is the thickness of ice that stood over the 6,500 ft. contour of the Remarkables. An examination of our modern glaciers shows us that a considerable thickness of ice seems incapable of abrading or modifying to any extent the surface over which it slowly glides, even when carrying a load of rock-fragments locked in its undersurface. From this premise we are compelled to conclude that the thickness of ice above the summit of the southern half of the Remarkables must have been very considerable—sufficient, at any rate, to give the necessary compressive stress to furrow and sculpture the mountain-summits at 6,500 ft., as we now see them.

The country rock is a semi-metamorphic mica-schist, often friable and crumbling on weathered surfaces ; but when worn down to the fresh rock, as it would be by ice-abrasion during the glacial period, it is found to be tough and resistant, as strong perhaps as the sandstones used for building purposes in Great Britain—such as the Arbroath, Dean Forest, Polmaise, Blue Hailes, Darley Dale, and other well-known building-stones—possessing an ultimate crushing-strength varying between 400 tons and 600 tons per square foot.

These sandstones, it should be noted, are only of moderate strength compared with such rocks as the Potomac Red Sandstone of United States, with a crushing-strength of 1,223 tons, and the Molasse Sandstone of Kempten, 1,850 tons per square foot. The crushing-strength of Welsh clay-slate ranges from 700 to 1,000 tons per square foot, and the mica-schist of Scotland from 400 to 650 tons.

If we assume that the mica-schist of the Remarkables is not more resistant than, say, the soft band of Chilmark Stone, of Tisbury, in Wiltshire—a weak building-stone somewhat resembling our Waikawa stone, with a crushing-strength of 100 tons per square foot—it is obvious that it would require a thickness of 3,500 ft. of ice to exert a pressure above the ultimate breaking-strength of the schist. But we have no warrant in supposing that any such thickness of ice existed above the 6,500 ft. contour. It seems impossible to avoid the conclusion that the sculpturing performed by moving ice must be mainly due to the abrading action of the rock-fragments locked in its lower surface, like the cutting-action of diamonds set in the soft-iron crown of a boring-rod. Without the requisite pressure on the revolving crown, the diamonds will not bite. Moreover, for effective work the pressure on the crown must be regulated to the hardness of the rock being bored.

Pure water is a perfect lubricant, and, even when running at a high velocity, exerts practically no erosive action on its channel. The cutting-power of running water is almost entirely dependent on the abrasion caused by the transported material.

In like manner our New Zealand experience of valley-glaciers shows that a considerable thickness of ice, containing no subglacial débris, may glide over its bed without modifying the surface on which it rests to any appreciable extent.

It seems improbable that moving ice will abrade its bed, unless the pressure of its own mass is sufficient to force the transported rock-fragments into the yielding surface below.

It is well known that even a revolving rod of soft iron will cut the hardest rock if sufficient pressure is exerted on it; and in the same way a moving sheet of ice should be capable of abrading its bed if the gravitational stress due to its mass exceeded the ultimate strength of the bed-rock. The rock-surface would fail and crumble, and the removal of the abraded material by subglacial streams would expose fresh surfaces, so that in time extensive rock-planing might take place through this cause, operating either alone or in conjunction with the disintegrating action of alternating freezing and thawing.

It will be seen from the foregoing that we are almost entirely without data that would enable us to estimate even approximately the thickness of ice that stood over the summit of the southern portion of the Remarkables, often spoken of as the Hector Range. It is doubtful whether the thickness exceeded 1,500 ft., although it might very well have been much greater; but it is equally improbable that it was less than 750 ft. during the period of maximum refrigeration, judging from the strongly marked evidences of ice-erosion found on all the mountains above the 5,000 ft. contour.

Taking a thickness of 750 ft. as surmounting the 6,500 ft. contour, we get a maximum thickness of ice in the Wakatipu basin of 7,490 ft., computed as follows:—

Hector Range, ice-eroded to	6,500 ft. above sea-level.
Floor of Lake Wakatipu	240 ft. below ,,
Thickness of ice-plateau above summit of Hector Range	750 ft.
Total	7,490 ft.

The thickness of ice in the Arrow basin, which lies at a height varying from 1,200 ft. to 1,400 ft., on this basis would be some 6,200 ft. Even assuming that the surface of the ice-plateau did not rise above the crest of the Hector Range—although we know that it must have done so—we get a maximum thickness of 6,740 ft. in the Wakatipu basin and 5,540 ft. in the Arrow basin, the latter exceeding the computed maximum thickness of the continental ice-sheet covering Scotland in the glacial epoch of the Northern Hemisphere.

The Motion of Glaciers.

The first true conception of the physics of glacier-ice was due to the genius of Canon Rendu,* afterwards Bishop of Annecy, who, in a memoir on the "Theory of the Glaciers of Savoy," contended that ice possessed a certain plasticity which enabled it to mould itself to its surroundings. Glaciers were, he argued, "rivers of solid water"; and, further on, when discussing the motion of what he terms *stream-glaciers*—now known as valley-glaciers—he says, "There is between the Glacier des Bois and a river a resemblance so complete that it is impossible to find in the glacier a circumstance which does not exist in the river."

Soon after—that is, in 1842—Principal James Forbes, the physicist, of Edinburgh, as the result of careful theodolite measurements made on the *Mer de Glace*, established the fact

* M. Le Chanoine Rendu. "Theorie des Glaciers de la Savoie," Mem. Soc. Acad. Savoy, x, 95, 1841.

that glaciers moved more rapidly in the middle than at the sides and bottom ; and from these premises contended that glacier-ice, or firn, notwithstanding its brittleness and hardness, was in reality a slightly viscous mass, which flowed downward under the influence of gravity, like a stream of lava. Forbes's theory of ice-plasticity now finds general acceptance among geologists and physicists.

The movement of a glacier, like that of all viscous fluids, is now conceded to resemble in nearly all respects the flow of a river. For example, as proved by Forbes, the central portion of the surface travels more quickly than the sides or bottom ; and at the bends the rate of flow is greatest at the inner or convex side, and least at the outer or concave side. Like water, a thick stream of ice will flow faster than a thin stream on the same gradient. And, while the retardation of flow of a river at the sides and bottom due to frictional resistance is great, in a semi-solid like ice it must be enormous. The differential surface flow of a glacier is shown in the next diagrammatic plan, where the shaded lines enclose a glacier-bed of uniform cross-section having the same gradient throughout.

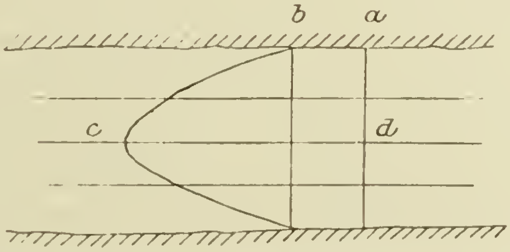

Fig. 9. Plan showing Differential Surface Flow of a Glacier.

The minimum flow is at the sides, being represented by the displacement *ab*, while the maximum flow is at the centre, being represented by the horizontal displacement *dc*. As a matter of actual experience it is found that, while the least flow is at the sides and the greatest at the centre, the flow at any point of the cross-section is liable to be modified considerably by the contour and gradient of different parts of the glacier-bed.

The differential rate of flow as between the surface and the bottom is shown in the next figure, which represents a longitudinal section of a glacier.

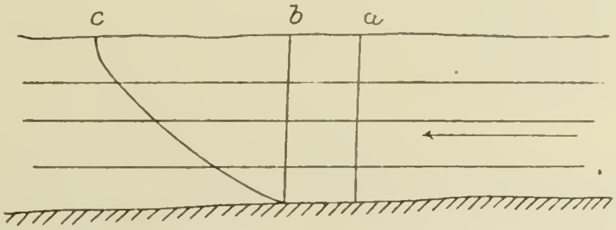

Fig. 10. Longitudinal Section showing Differential Flow of Glacier as between Surface and Bottom.

In the above figure *a b* represents the amount of horizontal flow or displacement at the bottom of the glacier, and *a c* the amount of flow at the surface in the same unit of time.

As the rate of flow is unequal, there will be a two-fold effect produced in the glacier: in the first place the upper layers of ice will overflow or override the lower, like the beams of a cantilever bridge, thereby throwing a greater compressive stress on the bottom layers; and in the second place the retardation of the lower layers will tend to cause rupture of the upper layers by tensional stress, which will result in the formation of a series of fissures or crevasses more or less at right angles to the line of flow. Such fissures will be widest at the surface, gradually narrowing in depth, and ending on reaching the zone of compressive stress. Thus it will be seen that for dynamical reasons it is unlikely that a crevasse should extend down to the bottom of a glacier of any magnitude.

Water placed on a plane descends through the action of gravity, the movement being due to the molecules sliding over each other. The author agrees with Professor Heim that gravity is the force which causes motion in a glacier.

According to Tyndall, the motion of glaciers is caused by *fracture and regelation*. That is to say, he believed the motion to be mainly mechanical rather than molecular. But his explanation, although it has received the support of many eminent authorities, is not very convincing. *Fracture and regelation* may possibly be the character of the motion, but it is impossible to conceive that they can be the cause. Take a uniform beam of steel, and rest it on supports; let the beam support no weight but its own mass; in course of time the beam will bend and become deformed under the stress of gravity—that is, under the influence of gravity the metal tends to flow along the plane of least resistance, until a permanent deformation takes place. No fractures appear on the surface of the metal, the flow being molecular and not mechanical.

The author has found by experiment that a uniform beam of ice placed on supports without a load slowly bends and becomes deformed, in the same way as a bar of steel or iron, without showing any evidence of fracture or even of external strain. Ice is a homogeneous substance, and there seems no valid reason to suppose that the flow is other than molecular, as it is in all viscous bodies.

Professor F. D. Adams, of McGill University, in some recent experiments on rock-flowage by the exercise of pressure, has shown that cylinders of Carrara marble, when enclosed in jackets of tough sheet-iron, and subjected to irresistible but increasing pressure, have passed, without cracking in their yielding jackets, from an inch in height to discs of half this altitude and of correspondingly increased diameter. The cylinders did not lose their cohesion, but moulded themselves like so much wax. When removed from the jackets the discs were found to be as solid and homogeneous as were the original cylinders.

The difference between the flow of a liquid (a viscous body) and a solid is one of degree only, for while water is rapidly, and viscous bodies slowly, displaced by gravitational stress alone, such rigid bodies as crystalline rocks can be made to flow like viscous masses when subjected to sufficient compression.*

From almost all points of view we must regard glacier-ice as a viscous body that obeys the fundamental laws of hydrodynamics.

The Excavating-power of Glaciers.

This is a subject on which there is still much difference of opinion. Subalpine lakes were claimed as the result of glacial excavation by Ramsay as far back as 1862,† but this view was not indorsed by his contemporaries Lyell and Murchison. At the present day, Bonney, Heim, and other distinguished glacialists, while admitting that glaciers are capable of wearing down the asperities of a land-surface, and of grooving, rounding, and planing all prominent obstacles that happen in their path, deny the power of ice to create new features. It can

* Professor J. F. Kemp. *Mining and Scientific Press*, 11th April, 1908.
† Quart. Jour. Geol. Soc., London, 1862, p. 185.

only, they contend, modify pre-existing land-forms, but cannot excavate rock-basins. On the other hand, such eminent geologists as Geikie and Penck are equally strong supporters of Ramsay's views.

After a prolonged examination of a region that has suffered profound glaciation, the author finds himself with a distinct leaning towards the views of Ramsay.

A hoe that is dragged along the ground does no useful work—it does not even abrade; but by exerting pressure on the handle it is made to scoop out the soil in its path. A glacier may be compared to a graving-tool, and, except its own mass is sufficient to exert an irresistible pressure, it will glide over or merely smooth or polish the surfaces over which it passes.

A summit-glacier, by reason of its wide sectional area and relatively wide bearing-surface, does not abrade the surfaces on which it rests. Its thickness can commonly be measured in hundreds and not in thousands of feet. It carries no rocky load on its back; and its method of wearing down and modifying its bed is by picking up the loose frost-shattered fragments of rocks in its path, and carrying them forward to its terminal face, where they are piled up like a huge talus. But it does not abrade, and for this reason striated stones are rarely found in the transported débris. The pressure of its mass relatively to its rubbing-surface is too little to cause abrasion, much less gouging or scooping.

Similarly, a valley-glacier with a wide bearing-surface relatively to its depth is incapable of exerting a scooping action. It does not always abrade, and in many of our mountain-valleys occupied by shrunken glaciers at the upper end it would be difficult to trace the former extension of the ice but for the morainic débris scattered along the floor of the valleys. None of the existing glaciers in New Zealand are capable of excavating their bed, and it is doubtful if any in Europe or America are more competent to do so.

It is obvious that a glacier can only excavate when a certain relation exists between the pressure of its mass and its sectional area. A sharpened carpenter's chisel, with a sectional area of, let us say, one-thousandth of a square inch, will cut effectively with a pressure of 40 lb. exerted on it, while the same chisel blunted so as to present a sectional area of ten-thousandths of a square inch with the same pressure will only scratch the surface of the wood. The chisel is only able to gouge a hole when the pressure exerted on the cutting-edge in a unit length of time so far exceeds the ultimate strength of the wood as to cause rupture of the resisting fibres. It is equally certain that ice can only excavate its bed when the pressure of its mass exceeds the ultimate crushing-strength of the bed-rock. A thickness of 4,000 ft. of ice is capable of exerting a pressure of about 100 tons per square foot, and 6,000 ft. a pressure of 150 tons per square foot.

The mica-schist in the Wakatipu basin has a crushing-strength that probably exceeds 100 tons per square foot when the rock is lying horizontally, but the load to cause the rock to fail will be much less when the strata are tilted so as to present an inclined edge to the pressure-load. It has been proved experimentally that a rock possessing a crushing-strength of 200 tons to the square foot will fail with a load of 100 tons when set at an angle of 30° to the line of force, and with a load of 75 tons at an angle of 60°.

From this it will be seen how incapable the pigmy valley-glaciers of to-day must be to excavate their bed. As gouging-instruments they are sufficiently rigid, but deficient in mass. With the superadded weight of the continental ice-sheet of the glacial period they would be converted into effective excavators.

A glacier is one of Nature's graving-tools. Even Ruskin, while doubting the power of ice to excavate rock-basins, admits " that a glacier may be considered as a vast instrument of friction—a white sandpaper applied slowly but irresistibly to all the roughness of the hill which it covers." Why, then, should we deny it the capacity to wear away the surface, and thus form basins, if sufficient pressure be exerted upon it for long enough? A continental ice-sheet, such as that which covered Otago and Southland and the greater part of the South Island, would certainly exert sufficient pressure to cause the glaciers or ice-coulters flowing through the narrow gorge-like valleys that prevail in the Wakatipu district to deepen their beds in favourable places, not so much by scooping as by the furrowing action due to the irresistible surface-abrasion. Moreover, any structural weakness that might have caused, or contributed to, the original selection of the site of the valley prior to the glacial epoch would also assist the glacier in its work of excavation.

It is not a little singular that Lake Wakatipu, as well as all the smaller lakes, lie in narrow gorge-like valleys of small sectional area relatively to the height of the enclosing mountains.

It does not necessarily follow that the Wakatipu glacier, when it was surmounted by and formed part of the great ice-plateau of Central and Western Otago, excavated the rock-basin in which the lake now lies. We know that the Wakatipu Valley existed prior to the glacial period, and there is good reason for the belief that its origin has a close relationship to the powerful faults that traverse each of the main arms of the lake. Not only did the valley exist, but it is possible, or perhaps even probable, that a lake occupied a part of the floor of the valley before the advent of the ice. The dominant lines of dislocation following the course of the valley, and the work already performed by the great river draining the valley, would render the task of the glacier in excavating its bed to the present depth of the lake less formidable than it might at first appear to be. Moreover, it must not be forgotten that the depth of the Wakatipu rock-basin is but a small fraction of the total depth of the ice that at one time stood over it.

Lakes Luna, Hayes, Moke, and Johnson are only exaggerated rock-tarns scooped out by ice in the floor of the valleys in which they lie. That some of them lie in the track of faults is not the cause of their formation, although the faults doubtless played a part in determining the situation and direction of the pre-glacial valleys in which these lakelets lie.

The Northern Limits of Ice-sheet.

The evidences of former glaciation are to be found from one end of the South Island to the other. In the region lying between Preservation Inlet and Dusky Sound the mountains have been eroded down to a sloping plane of moderate relief. In the mountainous area lying between Dusky Sound and Awarua Bay, in the rounded flowing outlines of the land-forms, in the deep fiords, hanging-valleys, corrie-lakes, ice-cirques, and coastal moraines we have ample proofs of a vast overriding sheet of ice. The evidences that a continuous ice-sheet stood over the Wakatipu region have already been narrated. The same proofs can be traced along the main axial divide until we reach Boulder Lake, in Collingwood County, in the northern part of Nelson, with its rock-cut basin, *roches moutonnées*, and moraines.

Seventy miles south of Boulder Lake we have Lake Rotoroa and Lake Rotoiti, both of which lie in rock-basins that are partly dammed up with morainic matter. The terminal moraine at the south end of Rotoiti is of vast proportions.

The piles of morainic and fluvio-glacial material, often mingled on the sea-face with marine sediments, afford conclusive proof that the glaciers reached the sea on the west-coast side of the South Island in the glacial period.

Evidence of a similar kind is not wanting on the east coast. Thus, the smooth rounded contours of the ranges and hills lying between Lake Wakatipu and the sea, the thick sheet of boulder-clay covering the Henley Hills and the area between Saddle Hill and Dunedin, and the silts and glacial till covering the Oamaru and Timaru areas afford convincing proof that the glaciers also reached the sea on the east coast.

The ice-sheet seems to have reached its northern limit near Cook Strait

Age of New Zealand Glacial Period.

In the Wanganui portion of the Province of Wellington we find a great succession of fossiliferous marine beds that date from older Pliocene up to the Pleistocene, with no evidence of a stratigraphical break.

The youngest marine beds known in the South Island are the Awatere beds in Marlborough and Greta beds in North Canterbury. These beds are older Pliocene. They are not known elsewhere in the South Island.

The absence of marine beds of younger Pliocene age in any part of the South Island, and the absence of all beds of older Pliocene age south of Waipara, give clear proof of a differential elevation of the South Island soon after the Miocene, the movement pivoting on the north end of the Island, being greatest in the south and least in the north. The absence of newer Pliocene beds shows that the elevation of the northern end was complete before the advent of that period.

The elevation of the land began in the newer Pliocene, and was accompanied by refrigeration that appears to have reached its maximum in the older Pleistocene, and it was doubtless in this period that the ice-sheet reached its northern limit.

After the retreat of the ice-sheet the mountain valleys and basins were still occupied by glaciers, some of which may have continued to extend as far as the sea for a time. But it is obvious that the amelioration of climatic conditions that caused the melting and recession of the ice-sheet could not be long in exercising a similar effect on the valley-glaciers, which soon began a grand retreat that did not cease until the confines of the mountain fastnesses were reached. There a halt was called, and behind piles of morainic material the glaciers made a stand of considerable duration. There is evidence that on two occasions* at least successful sallies were made beyond the sheltering ramparts; but the ground so gained could not be held. In a contest so unequal, retreat was inevitable. After the last sally, the now greatly attenuated glaciers began the last and final retreat, which ended in the total destruction of all but the few that were able to cling to the protecting flanks of the main alpine divide.

It was during the last retreat that New Zealand witnessed a period of hitherto unparalleled fluviatile activity. In this fluvial period—that is, in the newer Pleistocene—were formed the gravels of the Moutere Hills in Nelson, of the Canterbury Plains, the Southland Plains, and the inland basins of Canterbury and Otago. Contemporaneously with these were formed the great fluviatile and fluvio-glacial coastal terraces of Westland.

The Cause of the Glacial Period.

The refrigeration and later Pliocene elevation of the South Island were concurrent, a fact which makes it difficult to avoid the conclusion that the refrigeration was in part at least a result of the elevation.

When we examine the present-day conditions of glaciation in temperate regions we find that altitude is the dominating factor. Take the case of the New Zealand Alps, lying at our door. Here we have a block of mountains ranging from 8,000 ft. to 12,000 ft. high, that supports a number of valley-glaciers of considerable size. On the other hand, in the Wakatipu-Wanaka region, where the height of the mountains ranges from 6,000 ft. to 9,000 ft., we have no valley-glaciers, notwithstanding an equal precipitation and a mean annual temperature at least 1° Fahr. lower, resulting from the higher latitude. Only in two places do we find summit-glaciers—namely, at Mount Aspiring, 10,000 ft., and Mount Earnslaw, 9,000 ft. high.

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* James Park. "Geology of Alexandra Sheet," Bulletin No. 2 (New Series), N.Z. G.S., 1906, p. 11.

The mean height in the Mount Cook region may be taken at 10,000 ft., and in the Wakatipu–Wanaka area at 7,500 ft. Before considering these regions on equal terms we must first eliminate the difference of refrigeration due to latitude by applying the equivalent in height.

If we take the usual temperature-gradient of 1° Fahr. for every 300 ft. in height, we get 300 × 1 = 300 ft. Then, 10,000 — 300 = 9,700, and 9,700 — 7,500 = 2,200 ft., the height that would need to be added to the Wakatipu–Wanaka block of mountains to obtain valley-glaciers as large as those of Mount Cook region, the precipitation being taken as equal.

Assuming that a continuous ice-sheet could not exist above a mean temperature of 32° Fahr., and taking the mean temperature over the South Island at 42°, we get a difference of 10°, which would be equivalent to a height of 3,000 ft. Have we any evidence to justify the view that the South Island ever stood 3,000 ft. higher than at present ? Deposition of marine sediments has been in progress on the southern shores of the North Island ever since the older Pliocene, and it seems inconceivable that any general uplift of the South Island could have taken place without disturbing the North Island. It is well known that the slow differential uplift of the South Island that began at the close of the older Pliocene did cause the elevation of the newer Pliocene and Pleistocene sea-beaches along the shores of Cook Strait to a height of 300 ft. It might be argued that this uplift of 300 ft. is the equivalent of 3,000 ft. of elevation in Otago and Canterbury, resulting from the differential movement.

The measure of the uplift in the south of this Island might also be looked for in the drowned valleys that now form the fiords of south-west Otago. These valleys are pre-glacial, and were probably formed during the newer Pliocene uplift. Although deeply glaciated, we have no reason to suppose that their present form, except in rounded outline and greater depth, is different from what it was in pre-glacial times. How much of the present depth of the fiords is the work of ice-excavation is unknown and perhaps indeterminate, which thus makes it unsafe to venture even an approximate estimate of the general uplift on this basis.

The pluvial period, succeeding and following close on the heels of the Pleistocene recession of the glaciers, was one of general subsidence throughout the South Island, and it was during this subsidence that the great gravel plains of Canterbury and Southland were formed. It was this negative movement of the land in relation to the sea that gave the subglacial rivers of the newer Pleistocene their constructive power.

Summarising the evidence presented in the foregoing pages we find,—

(*a*.) That the Pliocene uplift of the South Island was accompanied by increasing refrigeration and glacier invasion.

(*b*.) That the Pleistocene subsidence of the South Island was accompanied by a corresponding decrease in refrigeration and a recession of the glaciers.

The relationship between elevation and the ice-invasion, and subsidence with ice-recession, is too marked to be lightly passed over. Uplift may not have been the sole cause of the glaciation, nor subsidence of the land the only cause of the softening of climatic conditions that caused the melting of the invading ice, but that they were the dominating factors seems to admit of little doubt.

An elevation of 3,000 ft. would have a far-reaching effect on New Zealand not only in respect to climatic conditions, but in relation to increase of area and uplift of submarine ridges that would tend to divert the equatorial sea-currents, and therefore cause a secondary but not insignificant modification of climate, which would accentuate the refrigeration due to the general elevation of the land.

The refrigeration that caused the glacial period of New Zealand may be ascribed mainly to elevation, and partly, as contended by some in discussing the contemporary glacial period of Europe and North America, to a shift or wandering of the polar axis of the globe ; but of this last we have no evidence, except that advanced by students of gravitational astronomy.

Ice-polished and Striated Rock-surface, Bob's Cove, Lake Wakatipu.
Photo Prof. J. Malcolm.]

Face of Boulder-clay, showing Rude Stratification, near Fernhill Coal-mine, Green Island, Dunedin.
Photo James Park.]

PLATE XXIV.

Face of Henley Boulder-clay, showing Rude Stratification, at Head of Gully behind Henley Hotel.

Photo A. Gordon Macdonald.]

The question may now be asked, was the great ice-plateau that covered the South Island of New Zealand an extension of the polar ice-sheet? It is almost certain that this must be answered in the affirmative, for, whatever cause or causes originated the glacial period in New Zealand would also operate in the higher latitudes. The exploring expedition of last November proved that the Auckland and Campbell islands had suffered intense erosion by an overriding sheet of ice that must have had a polar origin. (Articles and photographs, *Otago Witness*, December, 1907.)

Henley Boulder-clay.

This deposit possesses an extraordinary interest, from the circumstance that it affords conclusive proof that the glaciers of Central Otago at one time reached the sea on the east side of the South Island. Its glacial character has been acknowledged by Hutton,* Hector,† and McKay. It consists of yellow and red clays mingled with small fragments of quartz and mica-schist, among which occur occasional large masses of mica-schist as much as 10 ft. or 12 ft. in diameter. It extends from Otakaia southward to Waihola, forming the low coastal hills lying between the Taieri Flat and the sea. The main south railway to Invercargill skirts it for some miles. These coastal hills rise in places to a height of nearly 500 ft., but their height generally lies between 250 ft. and 350 ft. On its seaward side they are covered with water-worn gravels. The material commonly shows no arrangement, but this is not the case everywhere. At the head of the small gully lying behind Henley Hotel, in the steep escarpments that extend to the summit of the hill, the red clays and schist-fragments are distinctly arranged in rude beds or layers. As seen at this place in the steep cliffs, the material has a close resemblance to the boulder-clay deposits in the author's native country, especially to those in the valleys of the Dee and Don, near Aberdeen.

The Henley deposit is undoubtedly of glacial origin. It is not a terminal moraine, but a true boulder-clay, the formation of which appears to have been partly subglacial and partly subaqueous.

A sheet of boulder-clay of great interest covers all the hills and ridges between Dunedin and Saddle Hill. It consists of stiff yellow clay, which often contains boulders of basalt, phonolite, dolerite, and other igneous rocks.

Outcrop Curvature.

In the Arrow and Shotover valleys the mica-schist is a weak rock, inclined at angles that range from 40° to 60°. On one side the slope of the ridges is generally uniform with that of the angle of dip, but on the escarpment side, where the beds are without support, it is quite common to find the rocks bent over so as to dip in the reverse way, or bent and corrugated so as to appear to dip in many different directions even within a small area.

This bending of the rocks is the work of the ice-sheet that covered the mountains in the glacial period. It often obscures the true dip. On the slopes of the Coronet and Macandrew mountains, and in parts of the Richardson Mountains, it is impossible to get trustworthy observations of strike and dip over considerable areas.

Exfoliation of Striated Skin of Erratics.

The striated and polished surfaces of the large perched erratic near Hogan's Road, in the Arrow basin, shows a marked tendency to peel off in thin plates varying from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. thick, the plates, like a veneer, being flat, bent, or undulating, according to the contour of the

* Hutton. "Geology of Otago," 1875, p. 62.
† Hector. "Reports of Geological Explorations," 1890–91, p. 4.

striated surface. By gently tapping the surface with a hammer the striated skin can be peeled off without much difficulty.

An examination of the striated erratics lying on the Queenstown moraine disclosed the fact that they also exhibited the same tendency to peel off in thin plates.

All the erratics are composed of greywacke of fairly even texture. They vary from a few pounds up to 240 tons or more in weight, and commonly exhibit no bedding-planes or lines of stratification.

The exfoliation only takes place on the surface that has been polished and striated, and after the removal of the outer layer the rock exhibits no further tendency to exfoliate.

There seems some reason to believe that the striated skin is a layer of rock that has been reduced to a condition of internal molecular strain by pressure or stress exerted perpendicularly to the plane of exfoliation. If this contention be true, we have in this exfoliating skin a remarkable example of incipient cleavage induced by ice-pressure.

CHAPTER IV.

HYDROLOGY.

Rainfall a National Asset.

A generous rainfall, combined with a fertile soil and a temperate climate, forms the greatest national asset in the possession of New Zealand. At present much of the rainfall runs directly into the trunk rivers, and thence reaches the sea without performing any useful service to man. It is, however, only a matter of time when much of this surplus water will be converted to useful purposes, both in connection with agricultural and pastoral pursuits, and for the generation of motive power for various manufacturing industries that are now in existence or that will be created by the favourable conditions offered by a continuous and cheap water-supply.

The water-supply of the Dominion is a magnificent national endowment in perpetuity that will become of increasing value in the generations to come.

The natural fuel of the globe is becoming rapidly exhausted. Its exhaustion is even now within measurable distance. As coal becomes scarcer, water-power will more and more take its place, until when the day of exhaustion comes water will be the dominant motive power of the globe. Mountainous countries like New Zealand, that are endowed with a plentiful rainfall, are destined in the near future to become the workshops of the world. And this is already being realised in no small way in America, and in Norway, Sweden, Switzerland, and other parts of Continental Europe, where water is now being harnessed in place of steam for the generation of electric energy for manufacturing purposes of all kinds. New industries have been created and old industries rejuvenated. Streams that ran to waste for countless centuries have been found, in the conditions of the new civilisation, to have a high commercial value—a value that can be translated into an equivalent in £ s. d.

A never-failing supply of water is one of Nature's gifts to New Zealand, which is destined to become the workshop of the Southern Pacific. The Dominion possesses more water-power than the whole of the Commonwealth of Australia many times told; and a few generations will see the picturesque fiords of Otago converted into harbours throbbing with the hum and clang of industrial life. The rainfall is dependent on climatic conditions, and it may be preserved for all time by the conservation of the forests that clothe the slopes of the main alpine divide, where the water-supply is regulated by the melting of the winter snows. It may even be augmented by the judicious planting of trees in tracts of country that are now bare of forests.

The destruction of the forests in Westland, Canterbury, and Otago would be speedily followed by a diminution of the rainfall, and places that are now green and fertile would soon become arid and bare. A diminished rainfall means shrunken streams and dry water-courses; for the larger streams would be decreased in volume, while the smaller would become dry.

Central Otago presents a dire lesson of what may happen to a region denuded of its forests. It was in comparatively recent times covered with a dense forest up to an altitude of 4,000 ft The rainfall was abundant, and the surface of the country drained by large streams that could be counted by the score, and brooks by the thousand. At the present time, notwithstanding its fertile soil and sunny, temperate climate, it is little better than a wilderness seamed with dry watercourses, and must remain so until the parched-up soil is watered by irrigation.

The destruction of forests has a much greater significance than the immediate effect that results in a decrease of the rainfall. Careful and prolonged investigation in western and central Asia has shown that the denudation of mountainous regions of their covering of forest-vegetation sets in motion an arid cycle of long duration, which the puny efforts of man are hopeless to stem.

The preservation of our alpine and subalpine forests is a matter of national concern. To permit their destruction would be an everlasting crime, by inflicting a disability that could not but cripple the full and vigorous development of the nation for all time to come.

An asset can only be appraised at its true value when it has been fully ascertained, and in the case of New Zealand this can only be done by the continuous record of weather-observations at mountain stations, and by the systematic gauging of the flow of the rivers and streams.

The Americans, with the conspicuous enterprise and judgment they have shown in the development of their natural resources, have for some time past possessed a full realisation of the immense potentialities of their water-supply, and at the present time the Hydrographical Branch of the Department of the Interior is the best-equipped in existence. What has been done in America is now being imitated in parts of Continental Europe.

Stream-gauging, to be of any value, must be carried on continuously through a long succession of years. For the most part, isolated and spasmodic gaugings have little value. They are only useful for comparative purposes.

During the progress of the Geological Survey of the Queenstown Subdivision in the past summer, gaugings were made of most of the larger rivers and many of the smaller streams. The results, and the dates of gauging, are given below.

Gauging of Kawarau River.

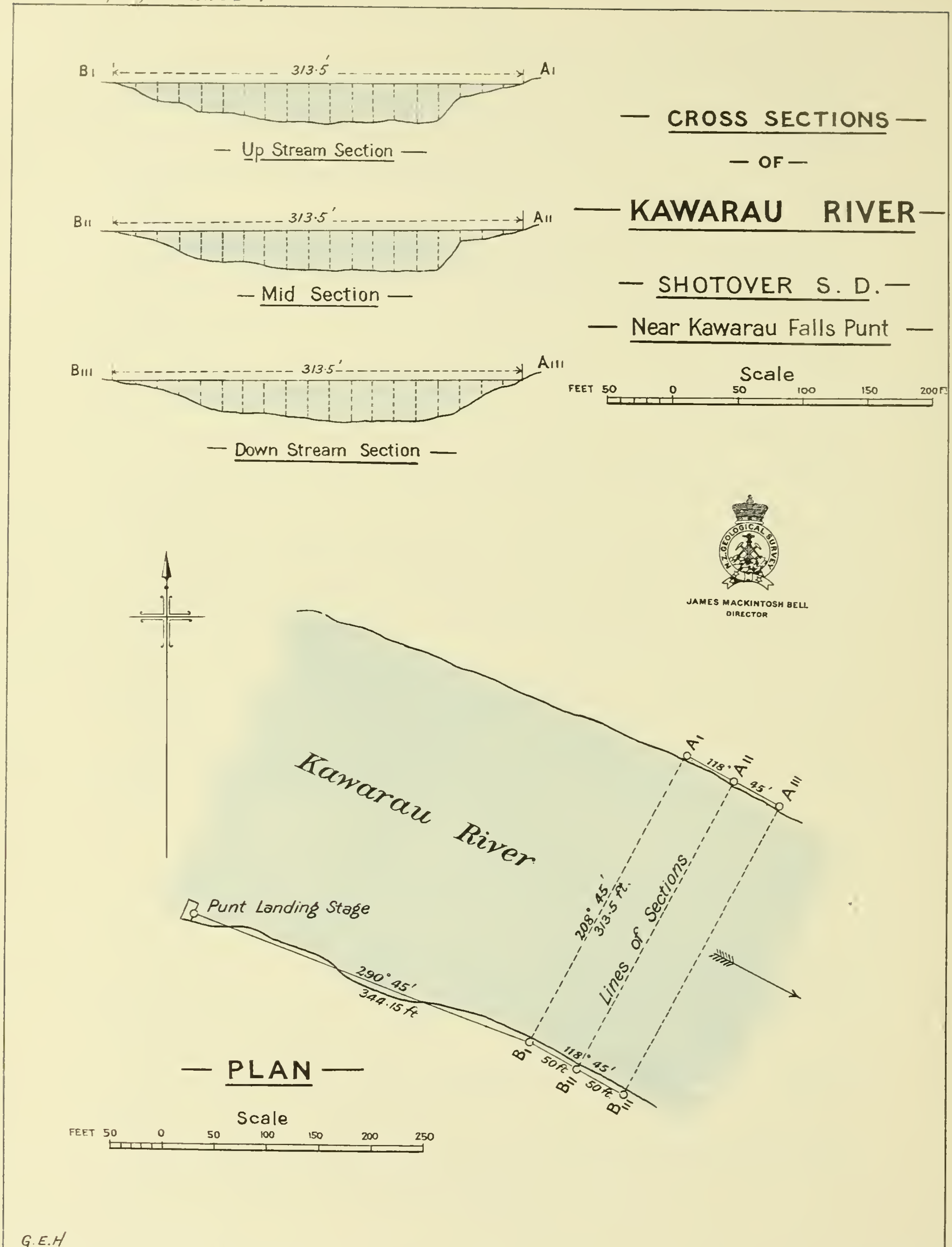
The gauging-station was selected at a point a few chains below the punt-ferry and half a mile below the Kawarau Falls, in order to be outside the influence of the rapids at the outlet.

Three lines of section were staked out on known bearings. The sections were 50 ft. apart, and the distance across the river between the stakes was 475 links. The sections were located at a point where the river-channel was straight for a quarter of a mile above the top section-line and half a mile below the lower line.

In order to ascertain how far the river-channel was of uniform cross-section both above and below the mid-section, soundings were taken along each section at intervals of 25 links, or 16·5 ft., the distances being measured from the bank by a steel tape, one end of which was held in the boat and the other on the shore.

The soundings were taken with a graduated rod up to 10 ft.; at depths over 10 ft. a sounding-line was used. The length of the sounding-line was carefully checked before and after use, and a correction made to the different soundings.

To accompany Bulletin No. 7



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The velocity-measurements were made with bottles and with loaded rods, the latter 5 ft., 8 ft., and 10 ft. long respectively. Two and often three measurements were taken at each sounding-point.

The soundings proved the river-channel to be remarkably uniform in sectional area and contour, as will be seen by a perusal of the plotted cross-sections facing this page.

The discharge has been computed in slices of 33 ft. The mean depth and mean velocity for each slice were found by the prismoidal formula as under :—

$$dm = \frac{a + 4b + c}{6};$$

$$Vm = \frac{Va + 4Vb + Vc}{6}.$$

The discharge through each strip is,—

$$Q = dmVml.$$

The mean depth and velocity in the strip near the bank was determined by the following formulas :—

$$dm = \frac{a' + a}{2}; \; Vm = \frac{Vo + Va}{2}.$$

Where

dm = mean depth in feet ;
Vm = mean velocity in feet per second ;
a, b, and c = consecutive depths at l feet apart ;
Va, Vb, and Vc = observed velocities at points a, b, and c ;
l = the width between points a, b, and c ;
Q = the discharge in cubic feet per second.

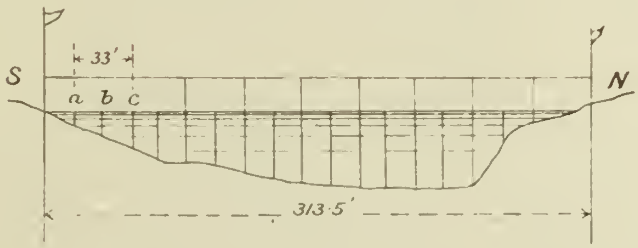

Fig. 11. Showing Strips and References used in computing the Discharge of Kawarau River.
S. The south bank. N. The north bank.

Statement of Depths and Velocities.—Measurements, beginning at South Bank.

Links.	Ft.	Mean Velocity, in Feet per Second.	Links.	Ft.	Mean Velocity, in Feet per Second.
0	0	0	250	165·0	2·73
25	16·5	0·40	275	181·5	2·75
50	33·0	0·61	300	198·0	2·73
75	49·5	0·95	325	214·5	2·56
100	66·0	1·36	350	231·0	2·24
125	82·5	1·70	375	247·5	1·83
150	99·0	2·05	400	264·0	1·36
175	115·5	2·48	425	280·5	0·80
200	132·0	2·51	450	297·0	0·34
225	148·5	2·64	475	313·5	0·00

The mean depth, mean velocity, and the discharge of each strip, deduced from the above figures, are as follows :—

Strip.	Mean Depth, in Feet.	Mean Velocity, in Feet per Second.	Discharge, in Cubic Feet per Second.
1	2·0	0·20	6·60
2	8·1	0·53	141·66
3	20·9	1·39	958·78
4	23·7	2·06	1,611·12
5	28·8	2·53	2,404·51
6	30·0	2·72	2,692·80
7	30·8	2·70	2,744·28
8	31·0	2·22	2,271·06
9	11·8	1·39	541·26
10	3·7	0·37	44·88
Total	..	..	13,416·95

Thus we find that the discharge of the Kawarau amounted to the great volume of 13,417 cubic feet per second.

The gauging of the middle line of section was done on the 11th March, 1908, and a datum-mark was cut into a stout blue-gum pile at the punt-platform, or landing-stage, on the north bank of the river.

A graduated plank has been fixed near this datum-pile, the 4 ft. mark on it corresponding to the datum of the gaugings taken on the above date. The river is not known to the oldest settler in the district to have fallen so much as 4 ft. below the datum, nor to have risen more than 6 ft. above it, which is the limit of the graduations.

Development of Power at Falls.

On the 11th March there was a difference of level of 5 ft. between the surface of Lake Wakatipu and the surface of the Kawarau River below the rapids at the outlet. With this fall a turbine would develop, with a discharge of 13,000 cubic feet per second, as much as 6,000 brake horse-power. But this amount of power could not be obtained continuously, as the damming back of the Kawarau by the Shotover during times of flood destroys the available head. For intermittent work the power would be of great value.

Discharge of Smaller Rivers and Streams.

The date of gauging, weather, and other conditions, as well as the discharge, are given in the following tabulated statement :—

Date of Gauging.	Name of Stream.	Discharge, in Cubic Feet per Second.	Remarks.
1907. Nov. 12	Coronet Creek	5·00	Fed by melting snow.
,, 14	Scanlon's Creek	3·75	,, ,,
,, 15	Bush Creek, above Macetown ..	4·00	,, ,,
,, 15	Goldburn (Twelve-mile)	18·00	,, ,,
,, 15	Arrow River, above Macetown junction	65·00	,, ,,
,, 20	Bracken's Creek	3·00	,, ,,

Kawarau Falls, showing Ice-worn Slopes of Queenstown Hill in Middle Distance.

Photo P. Malighan.]

DISCHARGE OF SMALLER RIVERS AND STREAMS—*continued.*

Date of Gauging.	Name of Stream.	Discharge, in Cubic Feet per Second.	Remarks.
1907.			
Nov. 21	Bush Creek, at Arrowtown ..	6·25	Fed by melting snow.
Dec. 7	Soho or Roaring Billy	12·00	,, ,,
1908.			
Feb. 6	Roaring Meg (Skipper's)	2·15	
,, 6	Old Man Creek	1·15	
,, 6	Right-hand Branch of Skipper's Creek	9·00	Fed by melting snow.
,, 7	Butcher's Creek..	3·25	At the minimum summer flow.
,, 7	Skipper's Creek, at mouth ..	14·50	,, ,,
,, 7	Main Branch, above Roaring Meg..	4·15	,, ,,
,, 8	Yates Creek (a branch of Stony Creek)	1·50	,, ,,
,, 8	Morgan's Creek	2·00	,, ,,
,, 8	Stony Creek	28·00	Melting snow.
,, 8	Gilbert Creek	4·25	
,, 9	Davidson's Creek	1·15	
,, 10	Deep Creek	6·00	
,, 21	Moke Creek	24·00	
Mar. 4	Maconachie's Creek	4·50	
,, 4	McGill's Creek	4·25	About minimum summer flow.
,, 9	Lake Hayes outlet	3·40	,, ,,
,, 9	Boundary Creek	6·25	,, ,,
,, 13	Walter Creek	3·00	,, ,,
,, 13	McKinlay's Creek	15·30	,, ,,
,, 18	Lucas Creek	4·75	,, ,,
,, 18	Afton Burn	55·00	,, ,,
,, 18	Von River	240·00	,, ,,
,, 19	Seven-mile Creek	1·25	,, ,,
,, 19	Five-mile Creek	4·15	,, ,,
,, 19	Eight-mile Creek	Dry.	
,, 25	,, ...	4·00	After rain.
,, 19	Ben Lomond Creek	4·25	,,
,, 19	Lake Dispute outlet	2·15	Summer flow.
,, 19	Lake Moke outlet	3·75	,,
,, 19	Right-hand Branch of Moke Creek	11·00	,,
,, 19	Bob's Knob Creek	2·00	,,
,, 19	Picnic Bay Creek	0·25	,,
,, 19	Echo Creek	2·15	,,
,, 24	Lake Luna outlet	4·25	,,
,, 24	Ben More Creek, at town end of Lake Luna	2·15	,,
,, 24	Lake Luna, First Hut Creek ..	1·75	,,
,, 24	Lake Luna, Second Hut Creek ..	1·20	,,
,, 24	Duke's Tarn outlet (near Lake Luna)	0·60	,,
,, 25	Twelve-mile Creek	9·00	,,
,, 25	Twenty-four-mile Creek	2·75	,,

CHAPTER V.

BATHYMETRICAL SURVEY OF LAKES.

General Procedure.

During the progress of the geological survey work, bathymetrical surveys were made of Lake Hayes, Lake Johnson, and Moke Lake. A survey and some soundings were also made of Lake Kilpatrick, a tarn not far from Moke Lake. From the data thus obtained the contour-plans and sections illustrating this chapter were constructed.

The lines of section along which the soundings were taken were fixed by line-traverses tied on to known points.

The soundings were made with a weighted steel tape graduated in links, and the sounding intervals determined by pulling so many strokes in a given time, the direction being maintained by ranging-flags fixed in the line of section.

Lake Hayes.

This is shaped something like a rough parallelogram. It has a mean length of about two miles, a mean width of some 45 chains, and an area comprising 655 acres. Its surface lies 1,080 ft. above the sea, or 65 ft. above Lake Wakatipu.

The 40 ft. contour follows the present shore-line very closely, and encloses 68 per cent. of the area of the lake.

The maximum depth obtained was 108 ft. The 100 ft. contour begins 66 chains from the south or outlet end, whence it extends north-east for 63 chains, ending 25 chains from the upper end. The mean width of the 100 ft. floor is 15 chains. Thus we find that an area $\frac{63 \times 15}{10} = 94{\cdot}5$ acres, or about one-seventh of the total area, lies at or below the 100 ft. level, and is almost flat.

The gradient of the floor at the outlet end is 1 in 43·56, and at the upper end is 1 in 16·5. Except at the lower end, the descent to the 50 ft. contour is everywhere comparatively steep, being commonly about 1 in 7

Lake Johnson.

This small lake lies embayed between the north end of Queenstown Hill and Ferry Hill, and is about a mile and a half north of the upper end of Frankton Arm. Its form, like that of Lake Hayes, is that of a rough parallelogram, running nearly north and south.

This lakelet lies at a height of 1,285 ft. above the sea, or 270 ft. above Lake Wakatipu. It drains into the Shotover, from which it is distant half a mile. The area is 70 acres.

The 40 ft. contour follows the present outline of the lake almost exactly, and encloses 71 per cent. of its area.

The deepest sounding obtained was 88 ft. The 80 ft. contour begins 9 chains from the south end, whence it extends northward for 32 chains, to a point 4·5 chains from the north or outlet end. The mean width of the 80 ft. floor is 6·25 chains, thus giving an area of 20 acres, or nearly 30 per cent. of the total area at that level.

The gradient at the south end is 1 in 7·4, and at the north end 1 in 3·7. The descent to the 80 ft. contour is steep everywhere, except at the south end.

The flow of the glacier that excavated this small rock-basin and Lake Hayes was from south to north, and it should be mentioned that in both cases the gentle slope down to the lake-floor is at the south end, and the steep slope at the north end.

Moke Lake.

This lake resembles two rough parallelograms joined at one end, forming a figure resembling a horse-shoe. It was excavated by two separate valley-glaciers that united at the outlet or northern end, forming a twin lake, a not uncommon feature in glaciated countries.

The surface of the lake lies 1,710 ft. above the sea, or 695 ft. above Lake Wakatipu. The length of each arm is about three-quarters of a mile, and the width of each about 20 chains. The total area is 240 acres.

The greatest depth obtained was 145 ft., in the west arm, near Wedge Point.

The area of the floor beneath the 140 ft. contour is 8 chains by 4 chains, and it lies immediately west of the end of Wedge Point.

The greatest depth obtained in the east arm was 84 ft. A considerable extent of this arm lies above the 40 ft. contour, much of it having been filled in by detritus shot into the lake by the small streams draining the western slopes of Ben Lomond.

In the western arm the gradient at the south end is 1 in 23·5, and at the north end 1 in 5·5. In the eastern arm the corresponding gradients are 1 in 33 and 1 in 5. Thus, as in Lake Hayes and Lake Johnson, we find the long slope in each arm at the end where the glacier entered the basin.

Lake Kilpatrick.

This is a small tarn situated a mile or two from Moke Lake, in the glacier-valley leading to Lake Wakatipu. It lies at a height of 1,790 ft. above the sea, or 775 ft. above Lake Wakatipu. It covers an area of 10·5 acres, and is quite shallow, the greatest depth being 12·5 ft.

Lake Wakatipu.

The bathymetrical survey of this lake was successfully carried out by Mr. Keith Lucas in 1902, and the results were embodied in a paper contributed to the *Geographical Journal* in 1904.

The first reference to the depth of Lake Wakatipu was made in 1864 by Mr. James McKerrow, sometime Surveyor-General of New Zealand, in a paper on the " Reconnaissance Survey of the Lake Districts of Otago and Southland."*

In this paper McKerrow refers to some soundings that had been made near Queenstown, where a depth of 200 fathoms was found. Sir James Hector, in the same year, in a map deposited in the Otago Museum, showed the positions of six soundings in Lake Wakatipu. In his paper on " Mining in New Zealand," published in 1869, Hector† states that the soundings varied from 1,170 ft. to 1,296 ft., and from these data concluded that the bottom of the lake was " nearly level from side to side, and from end to end."

In 1870, Mr. McKerrow,‡ in a paper on the " Physical Geography of the Lake Districts

* Jour. Roy. Geol. Soc., vol. xxxiv, p. 56.
† Trans. N.Z. Inst., vol. ii, 1869, p. 361.
‡ Trans. N.Z. Inst., vol. iii, 1870, p. 254.

of Otago," discusses the soundings taken by Hector, and refers to others taken by several persons independently. Of these last, the greatest depth is stated to have been 1,400 ft., found " about the middle of the lake, off Collins Bay, and sixteen miles from the south end of the lake.

The work done by Lucas occupied from the 1st October to the 7th November, 1902. Altogether 194 soundings were taken. Discussing the results of the soundings, he writes as follows :—

" The basin of Lake Wakatipu agrees with other features of the lake in showing a remarkable regularity. From the north end, or head of the lake, the bottom shows an unbroken fall, rapid at first, but constantly decreasing, for a distance of thirty-two miles. In the next nine miles beyond there is a level floor, forming the lowest depression in the basin : thirteen soundings were taken within this basin, and the extreme variation was 6 ft. The greatest depth found was 1,242 ft. From the southern end of the level depression the upward slope of the floor commences, and a fairly uniform rise over a distance of eight miles leads up to the shore at Kingston, the southern end of the lake.

" The maximum depth of 1,242 ft., which was obtained in 1902, does not agree with those which have been previously obtained. As has been stated above, in the account of previous soundings taken in the lake, depths of 1,296 ft. and 1,400 ft. are recorded The latter depth, in particular, is said to have been found about the middle of the lake, off Collins Bay, and sixteen miles from the south end of the lake. At the time when soundings were being made in 1902 the general belief among the inhabitants of Queenstown was that the deepest water was to be found off Collins Bay, and for this reason a line of soundings was taken at that point, one sounding being placed midway across the lake, at a distance of between fifteen and sixteen miles from the south end of the lake ; but no evidence was found of water of a greater depth there than elsewhere.

" Contour-lines have been drawn in the plan which accompanies this paper, at intervals of 200 ft. of depth within the lake-basin. An examination of these contours will serve to illustrate the gradients of the lake-floor from end to end, and for this purpose the distance between successive contours, from the head of the lake to the south end, are given below in tabular form :—

				Miles.
" Shore	to	200 ft. contour	.. ..	0·3
200 ft. contour	to	400 ,,	.. ..	0·5
400	,,	600 ,,	.. ..	2·7
600	,,	800 ,,	.. ..	5·3
800	,,	1,000 ,,	.. ..	6·3
1,000	,,	1,200 ,,	.. ..	9·7
1,200	,,	1,200 ,,	.. ..	17·4
1,200	,,	1,000 ,,	.. ..	1·3
1,000	,,	800 ,,	.. ..	1·0
800	,,	600 ,,	.. ..	1·7
600	,,	400 ,,	.. ..	1·3
400	,,	200 ,,	.. ..	1·0
200	,,	shore	.. ..	0·5 "

Here we have, in as marked a degree as in the case of Moke Lake and Lakes Johnson and Hayes, a long, gentle slope at the upper end of the basin, and a rapid slope at the lower end. It must be something more than a mere coincidence that all the glacial lake-basins in the Wakatipu area of which we have soundings have a gentle slope at the end at which the glacier entered, and a rapid slope at the other end.

The bathymetrical survey of the lakes of Scotland shows that Loch Ness and other lakes possess the same feature. It would be interesting to know whether we are dealing with a principle common to all glacial lake-basins.

CONTOUR PLAN OF

LAKE HAYES

SHOTOVER S.D.

Contour Interval - 10 Feet

— SCALE —

CHAINS 10 0 50 100 CHAINS

JAMES MACKINTOSH BELL
DIRECTOR

Bathymetrical Survey by E.F. Roberts

G.E.H.

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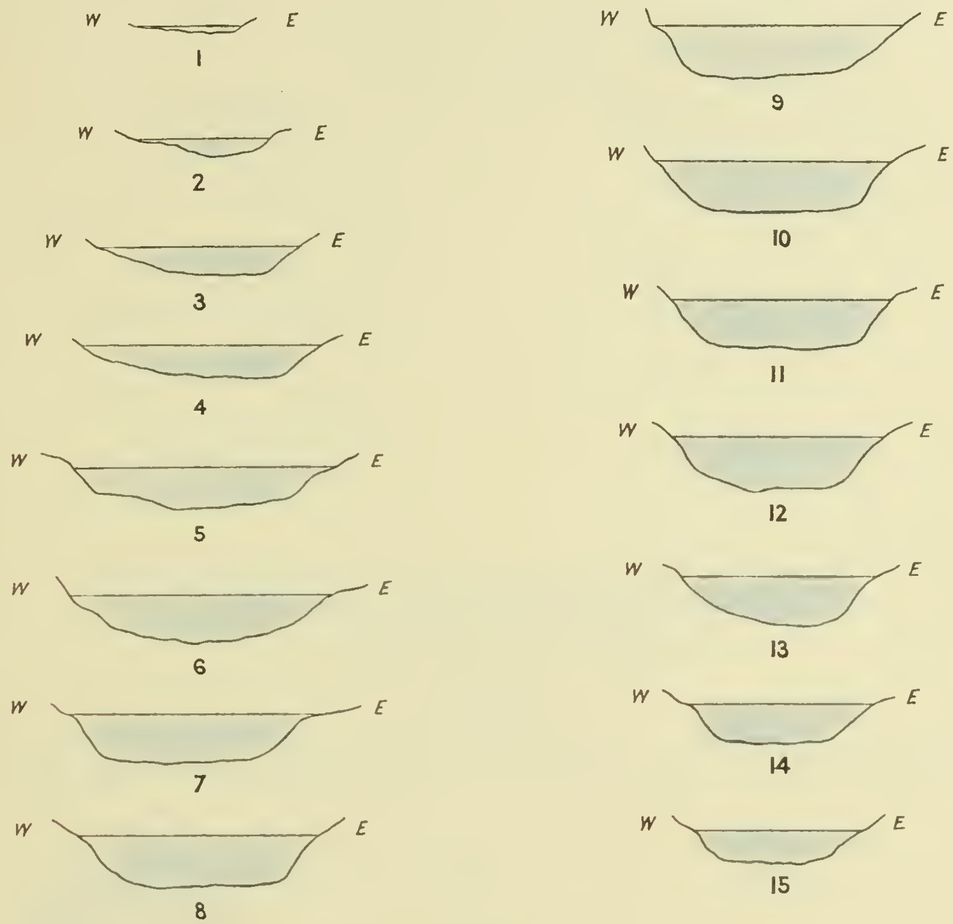

— CROSS SECTIONS OF —
— LAKE HAYES —

—— LONGITUDINAL SECTION OF LAKE HAYES ——

JAMES MACKINTOSH BELL
DIRECTOR

—— SHOTOVER S.D. ——

— SCALES —

HORIZONTAL

CHAINS 10 0 10 20 30 40 50 CHAINS

VERTICAL

FEET 100 0 100 200 300 400 500 FEET

Bathymetrical Survey by E.F. Roberts

G.E.H.

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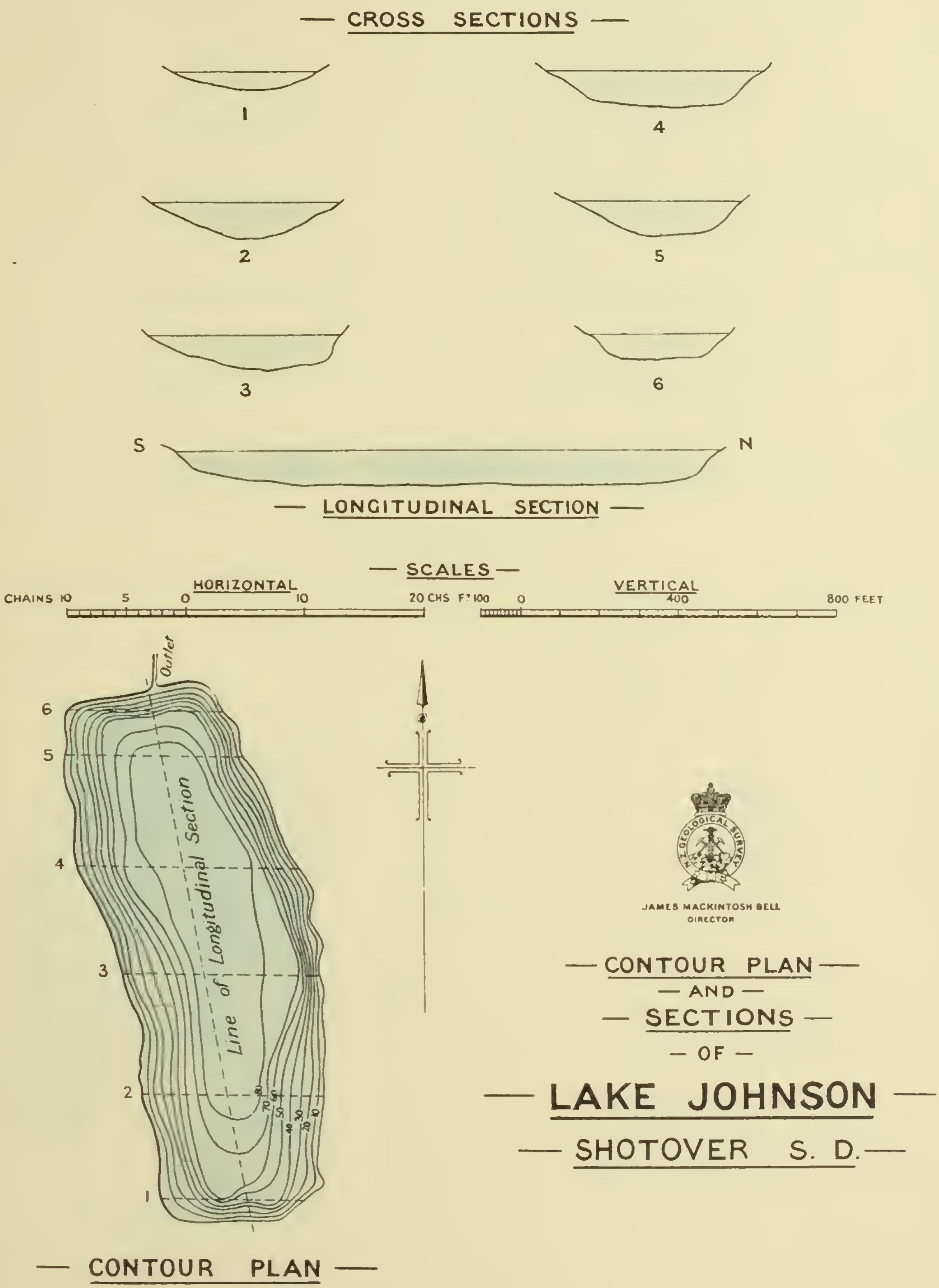

Bathymetrical Survey by H. Hamilton G. E. H.

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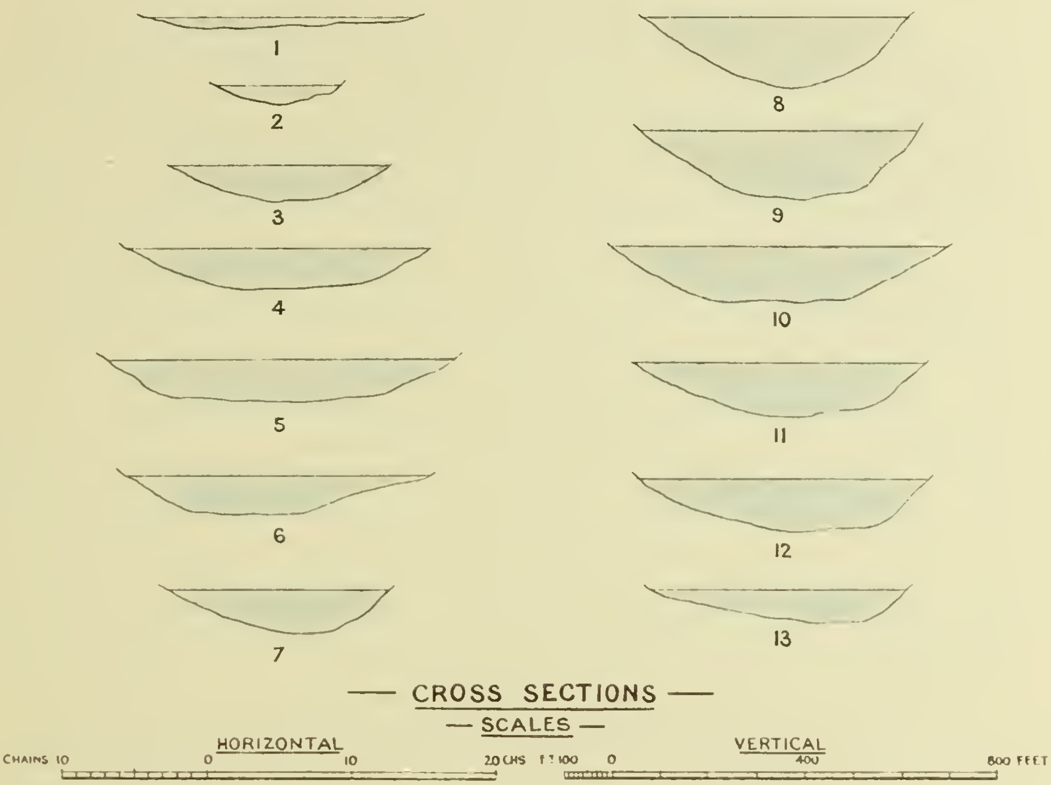
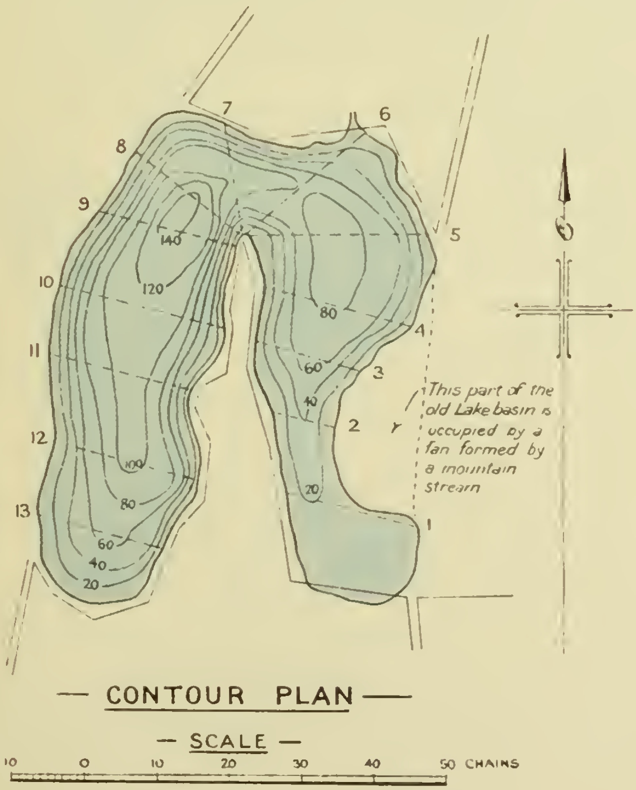


— CROSS SECTIONS —

— SCALES —



— CONTOUR PLAN —

— SCALE —

JAMES MACKINTOSH BELL
DIRECTOR

— CONTOUR PLAN —
— AND —
— CROSS SECTIONS —
— OF —

— MOKE LAKE —

— MID-WAKATIPU S.D. —

Bathymetrical Survey by H Hamilton　　　　*G. E H.*

By Authority : John Mackay, Government Printer.　　　　1250.12 08 825

Lucas, when discussing the shape of the Wakatipu basin, says,—

" Transverse sections, taken at almost any part of the lake, resemble one another to a remarkable degree. They show steep slopes leading down from opposite shores to a wide level floor, of a width equal to, or greater than, half the width of the lake at surface-level. This characteristic trough-like formation is most marked where the depth is considerable. Within the 800 ft., the 1,000 ft., and the 1,200 ft. contours, for example, the level floor at some points occupies as much as 50 per cent., 60 per cent., and 70 per cent. of the surface-width. And even in shallower water a similar formation is evident, though to a less extreme degree.

" There is but little special description needed to modify the general scheme of the lake-basin which has already been laid down, for the regularity of the basin is disturbed in but few places. The two larger islands, Pigeon Island and Pig Island, which lie in the north arm, are connected by a shallow bank, while the smaller, Tree Island, which lies to the west of them, is separated from them by water of greater depth, probably exceeding 200 ft. The whole group lies within a projecting arm of the 400 ft. contour, which runs in a southward direction from the eastern shore. The channel between the eastern shore and the islands exceeds 400 ft. in depth, except in its most northern part, while between the islands and the western shore there is a continuous channel over 600 ft. in depth.

" The Frankton Arm barely passes a depth of 100 ft. at any point, and is separated from the main body of the lake by a barrier, over which there is little more than 60 ft. of water. Queenstown Bay is also shallow, and its mouth is also crossed by a barrier. The other more open bays which the lake contains showed, as far as special soundings were made in them, a regular deflection of the contours, which calls for no special mention.

" The volume of water in Lake Wakatipu, as calculated from the areas included between successive isobathic contours, is 15 cubic miles, and the mean depth is 707 ft."

The areas of the lakes of which soundings were made under the supervision of the author of this bulletin, and the number of soundings taken in each, are given below :—

Name of Lake.	Area, in Acres.	Number of Soundings.	Number of Soundings.	
			Per Acre.	Per Square Mile.
Hayes	655	72	9·1	70·4
Johnson	70	22	3·2	201·1
Moke	240	40	6·0	106·6
Kilpatrick	10·5	6	1·7	365·7

CHAPTER VI.

GENERAL GEOLOGY:

Table of Formations.

The geological formations represented in the district are shown below in tabulated form in the order of their age and superposition :—

Recent,—
- River-beds, alluvial flats, swamps, &c.

Pleistocene,—
- *a.* Terrace-gravels, old fans, and modified glacier-drifts.
- *b.* Boulder-clays and moraines.

Lower Miocene,—
- Oamaru Series—
  - *a.* Sandstones and conglomerates.
  - *b.* Limestone.
  - *c.* Marly sandstone.
  - *d.* Marly clays and marls.
  - *e.* Calcareous breccias and conglomerate.

Palæozoic,—
- Kakanui Series—
  - *a.* Mica-schist, altered greywacke, and mudstone
- Maniototo Series—
  - *a.* Mica-schist, with bands of chlorite-schist.

Igneous,—Absent.

Maniototo Series.

Distribution.—This formation occupies the whole of Soho, Skipper's Creek, and Shotover survey districts, and the eastern portion of the Mid-Wakatipu district. It has now been traced continuously from the Puketoi Range, on the west side of the Maniototo basin, north-westward to Mount Aurum and the sources of the Shotover River, a distance of over eighty miles. The continuation of the northerly course will carry it into the upper part of the Rees Valley, and thence across the back of Mount Earnslaw to the sources of the Dart and Arawata rivers.

Rocks.—The Maniototo Series is composed mainly of mica-schist, which occurs in endless variety. Thus we have a soft flaky or flaggy silvery-grey mica-schist, prominently represented in the Skipper's, Lower Shotover, Arrow, and Macetown districts. It is for the most part composed of thin paper-like laminæ of micaceous matter and quartz, and is a weak rock, being friable, crumbling, and easily bent, as witness the manner in which it has been crushed, bent, and distorted by the pressure of glacier-ice on the slopes of Coronet Range on the road leading up to Skipper's Saddle; or bent and turned over by the pressure of its own mass, as in the gorge of the Arrow River on the road to Macetown, where we have, soon after leaving Arrowtown, some beautiful examples of outcrop-curvature.

In some places the quartz laminæ predominate—that is, they occur in thicker laminæ than the micaceous matter, and, being less continuous than the latter, sometimes impart a gneissoid appearance to the weathered outcrops. They commonly vary from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. thick, but laminæ over $\frac{1}{2}$ in. thick are not uncommon. The quartz occurs in short irregular sheets or flat lenses, that run in and out in a confused manner. This quartzose mica-schist is a strong rock, and splits readily into both thick and thin flags.

In a few places the micaceous matter is entirely replaced by quartz, forming a quartz-schist that is generally more or less micaceous. This is an intensely hard rock. It is not uncommon in the lower horizons of the Maniototian, but seldom occurs in bands more than a few feet or a few yards thick. It is in these bands of quartz-schist that we find the beautiful pink or flesh-coloured micaceous quartz-schist that has been described by the author among the gravels of the Arrow, Kawarau, and Clutha rivers in Bulletins Nos. 2 and 5.

The impression conveyed to the mind by the examination of the mica-schists in this and adjoining districts is that they are rocks that have suffered an intense degree of metamorphism.

From the Maniototo basin to the western slopes of the Dunstan Range, fringing the Cromwell basin, the strong quartzose variety of mica-schist predominates; but on Pisa Range, and going westward towards the Crown Range, the softer grey silky variety becomes more and more in evidence, until, when we reach the upper end of the Kawarau Gorge, it is the predominating rock. From this transition we gather that the original sediments were mainly arenaceous in the south, and mainly argillaceous in the north, the former marking shore-line, the latter deep-water conditions of deposition.

Intercalated in the mica-schist there are several bands of chlorite-schist, or of mica-schist coloured a pale green with chloritic matter. These chloritic bands occur in all parts of the Maniototian, but are most common in the lower portion.

At the western boundary of the Kawarau district, where it adjoins the Shotover district, there was noted by the author in the summer of 1906–7 an apparent thickening not only of the mica-schist, but also of the intercalated bands of chlorite-schist.* The detailed examination of that area during the past summer affords conclusive proof of a very remarkable thickening of the chlorite-schist, to which further reference will be found below.

In their upper part the mica-schists become less and less altered, and pass insensibly into altered greywacke, often laminated and veined with quartz, and flaggy micaceous claystones also seamed with quartz.

The lower half of the Maniototo Series in the Kawarau district is intercalated with six bands of chloritic mica-schist, varying from a few feet to a few yards wide.

* James Park. "The Geology of Cromwell Subdivision," Bulletin No. 5 (New Series), N.Z. G.S., 1908, p. 3.

In a few places the chloritic matter predominates, the rock in these cases passing into a chlorite-schist.

On the western slopes of the Crown Range, fronting the Arrow, the lower bands begin to increase in thickness in passing northward, the increase being so rapid that when the Arrow River is reached the total thickness of chlorite-schist is somewhat over 1,600 ft. The chloritic-schist outcrop extends from a point a few chains north of Bracken's Creek to a point some 15 chains from the Soho junction, and, as the river and the road pass over the outcrop almost at right angles to the strike, a very clear sectional view is obtained

The chlorite-schist does not occur in a continuous band. In its upper part it is interbedded with four beds of mica-schist, with an aggregate thickness of about 370 ft. The actual thickness of the chlorite-schist, exclusive of the mica-schist bands, is about 1,200 ft.

Following northward along the strike the chlorite-schist decreases in thickness in the most remarkable manner, so that in little better than a mile its thickness does not exceed 50 ft. In other words, the chlorite-schist occurs in the form of a lens about two miles long, which is, curiously enough, cut through by the Arrow River at its widest part.

Proceeding up the Soho, whose course is a continuation of the Arrow Gorge, the chlorite-schist is met with a few chains from the Arrow junction, and is beautifully exposed in cross-section on the banks of the Soho for a distance of nearly half a mile.

The chlorite-schist exposed in the Soho has an aggregate thickness of some 1,200 ft., and occurs in the form of a rapidly tapering lens. There can be little doubt that the Soho band of chlorite-schist is a repetition of the Arrow band.

With the chlorite-schist there sometimes occurs a thin streak or band of a dark-grey actinolite-schist, which passes into a quartz-schist, in which sheaves of pale-green actinolite are fully developed.

Disposition and Thickness of Strata.—The mica-schist, as seen in sectional view, is everywhere in this area free from apparent tectonic folding, but, on the other hand, is traversed by a series of powerful faults and thrust-planes, so that, while the continuous dip from Macetown to Lake Wakatipu would seem to indicate great simplicity of structure, the closer examination shows that the dislocations have introduced complications that the casual examination does not disclose.

The general strike is between north-north-east and north, and the dip regularly to the westward from Macetown to Lake Wakatipu.

The Arrow fault runs nearly parallel with the strike of the schists. Its vertical displacement must have been considerable, as it has caused a repetition of the great lens of chlorite-schist that occurs near the junction of the Arrow and Soho.

The Shotover fault follows a nearly north-and-south course; and, judging from the great thickness of crushed rock along its walls, the movement and pressure of which it is the resultant must have been very great. In the absence of a distinctive stratum or bed of schist displaced by it, there is no standard of measure by which the amount of movement or displacement can be determined. There can be no doubt, however, that such a powerful fault must have caused a considerable vertical displacement of the schists which it traversed.

The great Moonlight thrust-plane, along which the Miocene Tertiaries are involved, runs parallel with the Shotover fault, and almost parallel with the strike of the schist. Its dip seems to coincide with that of the schist.

The mechanics of the movement that entangled the long thin wedge of marine sandstone and conglomerate along this dislocation is not quite easy to explain. That it followed the movement of simple faulting is altogether improbable. Hence we must fall back on the hypothesis that the great fold whose axis was nearly parallel to the Miocene shore-line, on which the conglomerate was formed, was pushed over from the westward, overwhelming and entangling in its embrace, as it became bent over, a wide slice of the Tertiary rock.

The extraordinary manner in which the Tertiary strata at Bob's Cove are twisted and warped affords ample evidence of earth-movements on a profound scale after the close of the Miocene and some time before the advent of the glacial period.

When a succession of overthrust-folds close on each other, a continuance of the disturbing tangential stress must result in shearing, the tendency of the movement being to push one fold over the other. Such shearing, which is only a form of faulting, will be more liable to take place along the troughs of the folds in the line of compression than along the arches of the anticlinals, which will be in tension.

The Moonlight wedge of Tertiaries runs parallel to a plane of dislocation, along which a considerable amount of displacement has taken place, as the great width of crushed and shattered mica-schist on the foot-wall of the Miocene wedge on Mount Gilbert and elsewhere bears ample witness.

The Shotover fault or Pug lode, the Arrow fault, and the Moonlight shear-plane, whatever the mechanics of their movement, make it clear enough that the increase in thickness of the schists, which the continuous westerly dip might seem to imply, is apparent, and not real. The repetition of the great band of chlorite-schist at the junction of the Arrow and Soho is sufficient proof of this alone.

The presence of the faults, the shearing and overfolding, make it almost impossible to compute the true thickness of the Maniototian schists. In the beautiful section exposed along the gorge of the Arrow River, from Arrowtown to the Soho junction, we have a continuous westerly dip for a distance of three miles and a half, at angles varying from 40° to 60°, with a mean angle not less than 50°. Here we have an apparent thickness of somewhat over 14,000 ft.

The Stony Creek section, from the Shotover Pug lode or fault to the wedge of Miocene Tertiaries under Mount Gilbert, exposes a very clear view of the mica-schist at right angles to the strike in a distance of three miles and a half. The dip is westward, at angles varying from 45° to 70°. The mean angle of dip for the whole distance is probably not much under 55°, which would give an apparent thickness of a little over 15,000 ft.

The greatest thickness of the Maniototo Series exposed in the Alexandra district is about 10,000 ft., and in the Cromwell area about 12,000 ft.* The greatest thickness in the Arrow and Shotover districts cannot be safely put at over 14,000 ft. or 15,000 ft.

The abnormal increase in thickness of the chlorite-schist near the Arrow and Soho junction is quite local. In a previous report it was suggested that the chlorite-schist was an altered contemporary basic volcanic.† The discovery of this huge lens would tend to strengthen that view, for it is only possible to account for it by assuming that it marks the site of a Palæozoic volcano, the outbursts of which were contemporary with the formation of the schists. The beds of mica-schist intercalated in the chlorite-schist would indicate that the eruptions, or, at any rate, the later ones, were of an intermittent character.

Petrology of the Schists.—The bulk of the mica-schist is a soft, silky, grey rock, consisting of thin alternating laminæ of quartz and micaceous matter. The laminæ are not regular or continuous, and are often wavy or finely corrugated. In many places the quartz laminæ vary from ⅛ in. to ¼ in. thick, and are in such cases conspicuous. In other places, but only in subordinate bands, the quartz almost entirely replaces the micaceous matter, the rock then passing into what might be termed a micaceous quartz-schist. This quartz-schist is commonly grey in colour, but in a few places it contains streaks and even bands of pink quartz from an inch to two or three feet thick. These bands of pink quartz-schist are never continuous for any great distance. The pink colour is due to the presence of minute pink-coloured crystals of quartz that are coloured with iron-peroxide.

* James Park. "Geology of Cromwell Subdivision," Bulletin No. 5 (New Series), N.Z. G.S., 1908, p. 25.
† *Loc. cit.*, p. 25.

In some places the quartz laminæ are absent or poorly represented, the rock in these cases having the appearance of a phyllite.

The mica-schist in which the laminæ are thin is the predominating rock in the Arrow and Shotover districts. It is a weak rock, and in the places where it has been subjected to great lateral pressure, which is generally in the vicinity of faults, it is minutely but regularly corrugated, and in these places presents a somewhat remarkable appearance, from the circumstance that the corrugations are not only uniform in width and parallel, but sharply angular instead of being rounded in the folds and troughs, as is commonly the case. The distance from the centre of the trough to the centre of the apex of a fold is generally three or four inches. The general effect of this peculiar angular corrugation when seen in cross-section is that of twilled cloth, suggesting to the mind the herring-bone stitch of needlewomen. It is well shown in Plate XXVI.

When examined under the microscope in thin section, the mica-schist is found to consist almost exclusively of quartz and a white sericitic mica arranged in irregular wavy laminæ. Rutile is always present, in thin sharply defined needles that are often nearly opaque. A few plates of an acid plagioclase-feldspar are present in each slide, and occasionally a little chlorite in pale-green scales and fibres.

The chlorite-schist is commonly a pale to dark green rock, often possessing a silky lustre. It is soft when unaltered, and fibrous. Magnetite is often present in large and small grains. The rock is often laminated and veined with quartz, and in many places contains irregular patches and bands that have been epidotized.

When viewed in thin slice the chlorite-schist is seen to consist of chlorite and quartz, with magnetite, rutile, and feldspar as primary accessory constituents, calcite and epidote as alteration-products. The chlorite occurs in scales that are often altered at the margins, while some are stained a reddish-brown with hæmatite. It may, perhaps, be an alteration-product of hornblende. Plagioclase is always present, and often in some abundance, generally occurring in large plates. The quartz occurs in flattened grains, arranged parallel with the foliation. Rutile is generally present, but is never abundant.

A fairly common rock in the gold-wash is a heavy, dense, dull, reddish-coloured rock thickly impregnated with magnetite. On examination with the microscope it is found to be a garnet rock.

Foliation of the Schists.—The planes of foliation coincide with the changes of lithological character of the rock-material, from which it is inferred that they coincide with the bedding-plane of the original sediments from which the schists were formed.

Origin of the Schists.—The field and laboratory examination proves that the mica-schist is composed of clastic materials that were originally arenaceous and argillaceous sediments, probably thin-bedded greywacke and mudstone. From the apparent greater thickness of the schists in the western part of Central Otago it was assumed last year that the shore-line of the Palæozoic sea, on which the sediments accumulated, lay to the westward. The apparent increase of thickness has been found to be due in great part to overthrust-folding, and not to the proximity of the ancient shore-line.

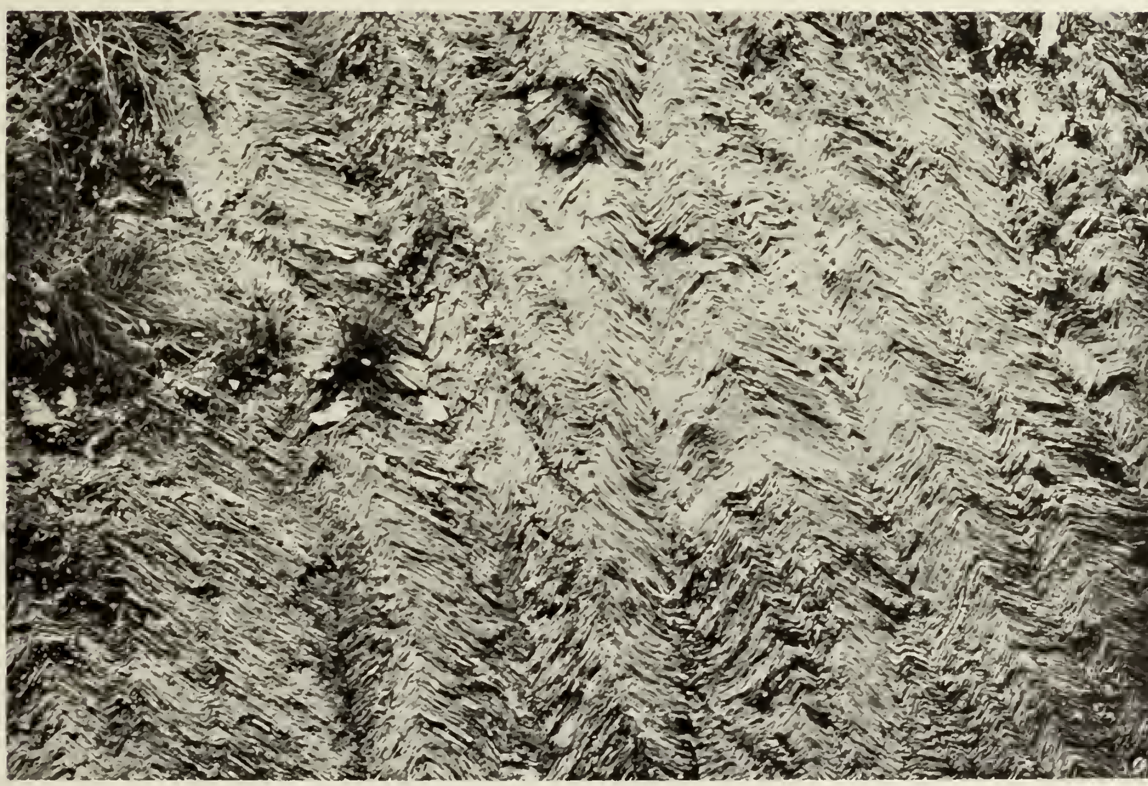
The past year's field-work proves that not only is there no real increase in thickness of the strata, but that the rocks become more and more argillaceous in proceeding westward, from which it may be contended that the shore-line of the Palæozoic sea lay somewhere to the eastward.

The composition, mineralogical character, and mode of occurrence of the chlorite-schist seem to show fairly conclusively that it originated from altered basic volcanic material of contemporary date.

Metamorphism of the Schists.—The Maniototian schists cover an area of some five thousand square miles ; and their ascertained thickness is over two miles and a half of strata. Through-

SHARPLY CRUMPLED MICA-SCHIST.

Photo James Park.]



HERRING-BONE CRUMPLED MICA-SCHIST, SKIPPER'S CREEK.

Photo James Park.]

PLATE XXVII.

Semi-metamorphic Mica-schist of the Kakanuian, with Quartz-laminæ, on Road from Queenstown to Five-mile Creek.

Photo James Park.]

out this wide area and thickness they are highly metamorphosed, and a striking feature of this profound metamorphism is its marvellous uniformity. Perhaps no less remarkable than the alteration and foliation of the sediments of this great formation is the almost complete absence of intrusive sills and dykes throughout its length and breadth.

The metamorphism is not contact or thermal. It is regional, and must be ascribed to dynamical agencies. The arguments in favour of this view have been fully discussed in Bulletin No. 5,* and need not be repeated.

Relationship to Underlying Formation.—The basement rocks of the Maniototian are nowhere exposed, and therefore no junction between them and the formation on which they rest can be examined. The character of the underlying formation is still unknown, and is not likely to be disclosed until the survey is carried over to the mountains of the main divide.

Age of the Schists.—The Maniototian schists contain no internal evidence bearing on their age. The age and character of the rocks on which they rest are still unknown, so that we have no means of limiting their age going downwards. On the other hand, we know that on the west side of Lake Wakatipu they pass upward into the semi-metamorphosed Kakanuian and Te Anaus, consisting of altered greywacke, argillite, phyllite, and conglomerates that are associated with serpentines and other basic igneous rocks.

Between Athol and Lumsden the schists are overlain by argillites that pass upward into fossiliferous claystones containing *Monotis* and other Triassic forms. The absence of the typical greywacke series in this area seems to show that an unconformity exists between the Triassic claystones and the underlying Kakanuian schists. At present it does not seem desirable to ascribe the Maniototian to any particular period. That they are Cambrian or earlier is almost certain, as at Collingwood they are overlain by rocks containing Ordovician graptolites.

Eruptive Rocks.—No eruptive rocks of any kind appear on the surface in the area under examination, but pebbles of hornblende-lamprophyre are fairly common in the gravels of the Shotover. Dykes of a black igneous rock are reported to occur among the mountains lying between the sources of the Shotover and the Matukituki Valley. They are probably the source of the pebbles and boulders of igneous rock spoken of above.

Economic Minerals.—This formation contains the gold-bearing veins at Macetown, Shotover, and Skipper's, and is economically the most important in Otago. Besides gold, it contains scheelite, copper, and antimony, the first of which is of great value. The minerals of economic value are fully discussed in the chapter dealing with "Economic Geology."

Kakanui Series.

Distribution.—The rocks of this series appear on the north shore of the middle arm of Lake Wakatipu, about two miles and a half from Queenstown, at a point a short distance past Picnic Bay. From there they form the ridges fringing the lake to the northern boundary of the district examined—that is, to the Twenty-five-mile Creek. All the rocks on the west side of the lake within the boundaries of the Mid-Wakatipu district belong to this series.

Rocks.—They generally consist of semi-metamorphic argillites and greywacke, in places passing into mica-schist, with occasional bands of phyllite and flaggy schist. The argillites and greywacke are often laminated with quartz seams that commonly run more or less parallel to the bedding-planes of the rock, and seamed with thin veins of white or grey quartz (see Plate XXVII).

In the upper part of the series the rocks are slaty and flaggy, and much less quartzose than in the horizon lying next to the underlying Maniototian. At the upper end of Lake

* James Park. Bulletin No. 5 (New Series), N.Z. G.S., 1908, p. 25, "Dynamical Origin of Metamorphism."

Dispute they are sometimes gritty and brecciated, while on Walter and Cecil peaks they pass into greywacke that is not much altered.

Relationship to Underlying Formation.—The rocks included in the Kakanui Series are merely the upper less-altered portion of the great metamorphic series of Central and Western Otago. They are perfectly conformable to the underlying Maniototian, from which they are not always easily separable.

Relationship to Overlying Formations.—In the district under review the semi-metamorphic Kakanuian is not overlain by or in contact with a stratigraphically superior formation.

At the mouth of the Greenstone River and at Rere Lake the rocks are slaty phyllites, often quartzose, and weathering a rusty-brown colour. Following up the Greenstone Valley, which for the first six miles runs west and south-west, the rocks exposed, in the order of their sequence, by the continuous westerly dip, according to Professor S. Herbert Cox,* are as follows :—

III. Indigo-blue slates.
IV. Red and green breccias, with heavy beds of green aphanite slate.
V. Dark-coloured jointed slates, with bands of black serpentine.

Among the large masses of rock in the great moraine lying between Rere Lake and the mouth of Greenstone River are many examples of a coarse conglomerate, composed mainly of large and small boulders of diorite, norite, granite, &c., and other crystalline rocks. This conglomerate has not yet been found *in situ*, but it probably belongs to the Takitimu Series, which is traversed by numerous dykes of diorite in the Eglinton country at the head of Lake Te Anau, or to the Wairoa Series, which at Hokanui Range and Nugget Point contains beds of a similar conglomerate.

From Athol southward, the Kakanui Series is followed by bedded claystones and greywacke that are not in the least altered, and bear a strong resemblance to the rocks forming the base of the Wairoa Series throughout other parts of Southland. The absence of the red and green breccias with heavy beds of green aphanite slate, and the dark-coloured jointed slates with bands of serpentine as seen in the Greenstone Section points to the existence of an unconformity between the Kakanuian and the Triassic Wairoas.

Age of Kakanui Series.—No fresh evidence has been adduced as to the probable age of this series, which is so intimately associated with the Maniototian that when the age of one is determined the age of both will be known.

Eruptive Rocks.—No eruptive rocks were found in the Kakanui Series in any part of the district, and none have ever been reported from it in any part of Otago. On the other hand, the overlying Te Anau Series is commonly intercalated with gigantic sills of dunite, serpentine, or diabase, and intruded by dykes of diorite, norite, &c.

Economic Minerals.—Veins of quartz and large well-defined quartz lodes are not uncommon in this formation. Many of the lodes were sampled and assayed for gold, but at the places examined none of them were rich enough to be profitable, but there is reason to believe that systematic prospecting will discover ore-shoots of good grade in some of them. The quartz lodes sometimes contain scheelite in profitable quantity.

Lower Miocene : Oamaru Series.

a. Sandstones and conglomerates.
b. Limestone.
c. Marly sandstone.
d. Marly clays and marls.
e. Sandstones, breccias, and conglomerate passing into limestone.

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* S. H. Cox. N.Z. G.S. "Reports of Geological Explorations," 1878–79, p. 53.

With the exception of bed *e*, which extends as a narrow strip from Bob's Cove to the Upper Shotover, the Miocene Tertiaries are confined to the vicinity of Bob's Cove, often spoken of as the Twelve-mile. Bob's Cove lies on the north shore of the middle arm of Lake Wakatipu, at a distance of some ten or eleven miles from Queenstown, and is reached either by a bridle-track following the shore of the lake, or by boat.

This small isolated patch of marine Miocene beds forms a sharp ice-shorn ridge, running parallel with the trend of the lake. Although less than half a square mile in extent, it presents some geological features of peculiar interest, more particularly in connection with dynamical problems, and mountain-building.

Involvement in Schists.

The lowest bed of the series, marked *e* in the tabulated statement above, is detached from the main body of the series, being deeply involved, as seen on the shore of the lake, among the Kakanuian schists, which are broken, shattered, and brecciated for a great thickness in the vicinity of Bob's Cove.

From Lake Wakatipu this strip of fossiliferous breccia-conglomerate extends in a northerly course to Moonlight Creek, thence across Mount Gilbert to Stony Creek, whence it proceeds in an almost direct course along the higher slopes of the Richardson Mountains to near the source of the Right Hand Branch of the Shotover, a total distance of twenty-five miles. It runs across hill and dale, rising in places to a height of nearly 6,000 ft. above the sea, in others descending to a little over 1,000 ft., but is not now continuous, having been removed by denudation in some of the deeper gorges.

It is a geological feature of extraordinary interest, and, so far as known at present, there is nothing comparable to it except the narrow wedge-like strips of nummulitic limestone (Eocene) involved in the Malm (White Jura) on the west side of the Jungfrau, in the Bernese Oberland, in Switzerland. It was first noted by Mr. Alexander McKay* in the year 1880, but its significance appears to have escaped the notice of Captain Hutton when discussing the mountain-building of the New Zealand Alps at a later date.

The section exposed on the margin of the lake on the east side of Bob's Cove is shown in Fig. 12 below :—

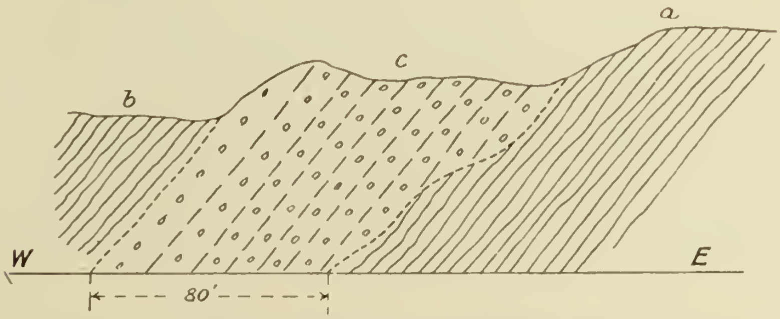


Fig 12.—Section near Bob's Cove, showing Wedge of Miocene Breccia-conglomerate involved in Schist, 65 ft. thick.

a. Quartzose mica-schist, strongly brecciated. *b*. Micaceous schist, much shaken and broken. *c*. Miocene breccia-conglomerate.

At this place the schist strikes north-and-south (true), and dips west at an angle of 53°.

* A. McKay. N.Z. G.S. "Reports of Geological Explorations," 1879–80, p. 145.

For a distance of 15 chains towards Queenstown—that is, going eastward in respect to the above section—the schist is strongly brecciated in wide zones, having been crushed into small angular fragments resembling road-metal, and afterwards recemented into a hard rock by the deposition of silica in the interstices.

The mica-schist on the west side of the Miocene wedge is soft, decomposed, and crumbling. It is overlain by the marly clays and other members of the Tertiary Series in orderly succession.

The breccia-conglomerate involved in the schist consists of angular and rounded pieces of the underlying schist set in a cement of yellowish-coloured limestone that contains many broken shells, among which fragments of a large oyster are conspicuous. It is well exposed at the point where it crosses the Twelve-mile Creek, about two miles and a half distant from the lake, on the ridge lying near the head of Seffer's Creek; at the points where it crosses Dead Horse, Moonlight, and Stony creeks; and on the slopes of the Richardson Mountains, between Stony Creek and the Left Hand Branch of Skipper's; and also at many intermediate places.

At the Moonlight crossing it is about 140 ft. thick, and consists of bands of breccia, sandstone, and limestone.

At the Stony Creek crossing it varies from 8 ft. to 20 ft. thick, and consists of hard siliceous sandstone passing into gritstone and conglomerate. Its strike is 5° (true), and its dip westerly at an agle of 70°. The outcrop at the point where it crosses Stony Creek is 1,800 ft. above the sea. The section exposed on the north bank of the creek is shown in Fig. 13 below:—

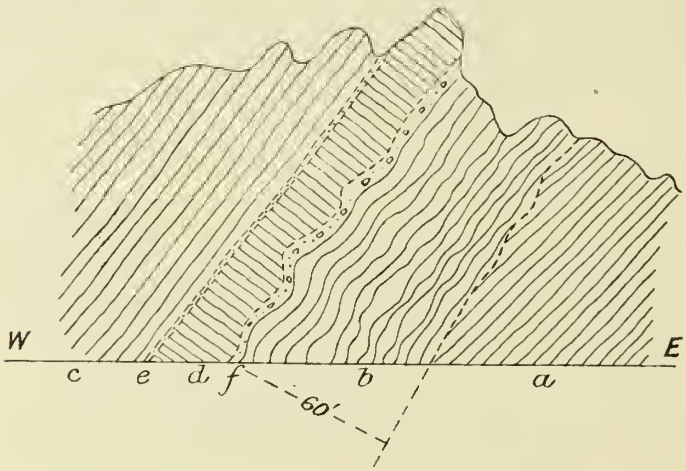


Fig. 13. Section at Stony Creek, showing Marine Tertiaries interbedded with the Palæozoic Schists.

a. Mica-schist, soft, crumbling, silvery grey. *b.* The same schist as *a*, but twisted, shattered, and contorted. *c.* Chlorite-schist, partially epidotized and silicified—a hard and strong rock. *d.* Tertiary fossiliferous sandstone. *e.* Thin band of stiff blue clay—crushed schist. *f.* Quartzose breccia—conglomerate passing into siliceous sandstone.

The wall next the chlorite-schist is even and straight; while that next the mica-schist, although well defined, is irregular or corrugated, and often strongly slickensided.

The section on the south side of the creek looking southward is shown in Fig. 14 :—

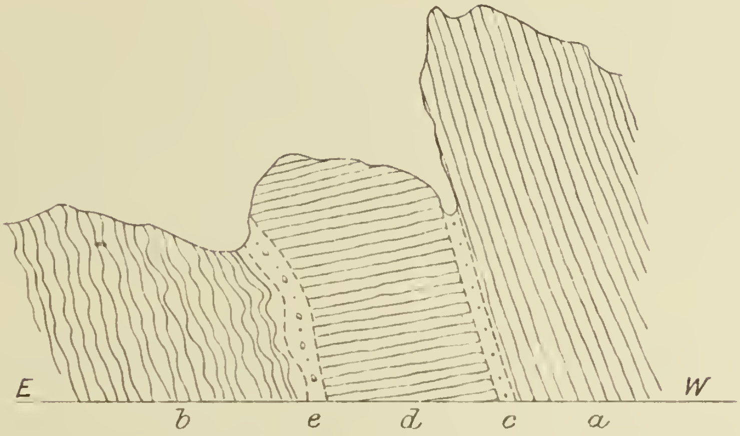


FIG. 14. SECTION SHOWING MARINE TERTIARIES INTERBEDDED WITH PALÆOZOIC SCHISTS AT STONY CREEK, NEAR FOOT OF MOUNT GILBERT.

a. Chlorite-schist. *b.* Mica-schist, soft and crushed. *c.* Band of stiff blue clay, with gritty particles of quartz from 8 in. to 16 in. thick. *d.* Grey siliceous sandstone, fossiliferous, 12 ft. thick. *e.* Quartzose breccia, from 2 ft. to 3 ft. thick.

On the north side the Marine bed varies from 14 ft. to 20 ft. thick, and shows a tendency to increase in thickness going northward.

The siliceous sandstone contains a considerable number of fossil-remains, among which were identified a *Venus*, *Pinna*, *Ostrea* (very large and thick, like *O. Wullerstorfi*), *Turritella*, *Natica*, a thin striated *Dentalium* like *D. Mantelli*, some corals and fucoid stems.

From Stony Creek the Marine bed runs northward along the eastern slopes of the Richardson Mountains towards Mount Aurum, and southward across the shoulder of Mount Gilbert to Moonlight and Lake Wakatipu.

Going northward from Stony Creek it rises very rapidly, the steep angle of dip carrying it on to the summit of the Silverhorn, which it crosses at a height of 5,300 ft. some 20 chains east of the highest peak. This is the greatest elevation at which rocks of Tertiary age have been found in New Zealand. It is not unlikely that they will be found at even a greater altitude on the northern end of the Richardson Mountains beyond Mount Aurum.

The fold in which the Tertiaries are entangled does not follow the strike of the schists, but passes obliquely across it, so that when the source of the Left Hand Branch of Skipper's Creek is reached the chlorite-schist forms the foot-wall instead of the hanging-wall, as at Stony Creek.

Depth of Involvement of Tertiaries.

Stony Creek is a great natural crosscut running at right angles to the trend of the mica-schist and its contained band of fossiliferous Tertiary sandstone. The latter is cut through in the bed of the stream, at an altitude of 1,800 ft. above the sea, and can be traced continuously, as if it were a member of the schist-formation, from the bed of the stream northward to the summit of the Silverhorn, which it crosses at an altitude of 5,300 ft.

Such profound involvement of a thin band of Miocene strata in a highly altered Palæozoic formation seems almost incredible, but the stratigraphical evidence could not be clearer, even if the Tertiary sandstone were a contemporary bed of coal interbedded in the schist.

But, obviously, 3,500 ft. does not measure the maximum depth of the infolding. The Silverhorn shows marks of extensive ice-erosion, and we are well justified in the belief that the outcrop of the Miocene rocks stood at one time many hundreds of feet higher than at present.

In the bed of Stony Creek the infolded rock forms a hard well-defined band, that might very well descend a considerable depth below the 1,800 ft. level

Going southward from Stony Creek the Tertiary band crosses the east shoulder of Mount Gilbert at a height of over 4,000 ft., and descends rapidly to Moonlight Creek, which it crosses at a height of 1,800 ft. above the sea. At Dead Horse Gully, still further south, it again reaches the same level, whence, crossing a spur descending from Ben More, it descends to the Twelve-mile Creek and Lake Wakatipu. On the shore of the latter it is 65 ft. wide, and looks as if it might descend for many hundreds of feet below the surface of the lake; but of this we know nothing.

From the surface of Lake Wakatipu, at some 1,000 ft. above the sea, to the shoulder of the Silverhorn, at 5,300 ft., we have an apparent involvement of 4,300 ft. But between Lake Wakatipu and the Silverhorn the schists might easily be faulted in such a way as to exaggerate the infolding of the marine beds, and for that reason we must rely on the Stony Creek section, where the entangled band is exposed in a beautiful transverse section for a vertical height of 3,500 ft., as shown in the next figure :—

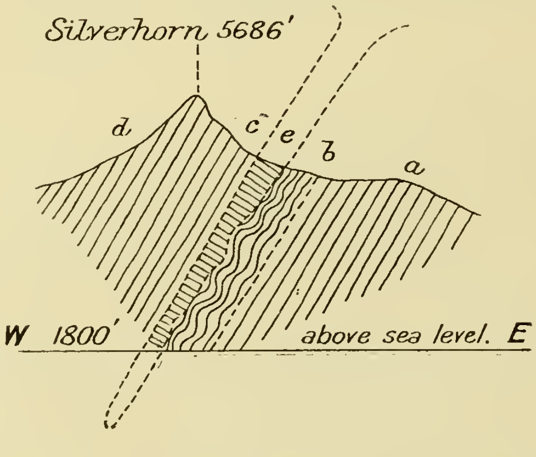


Fig. 15. Section at Stony Creek: Tertiary Beds involved in Schists.

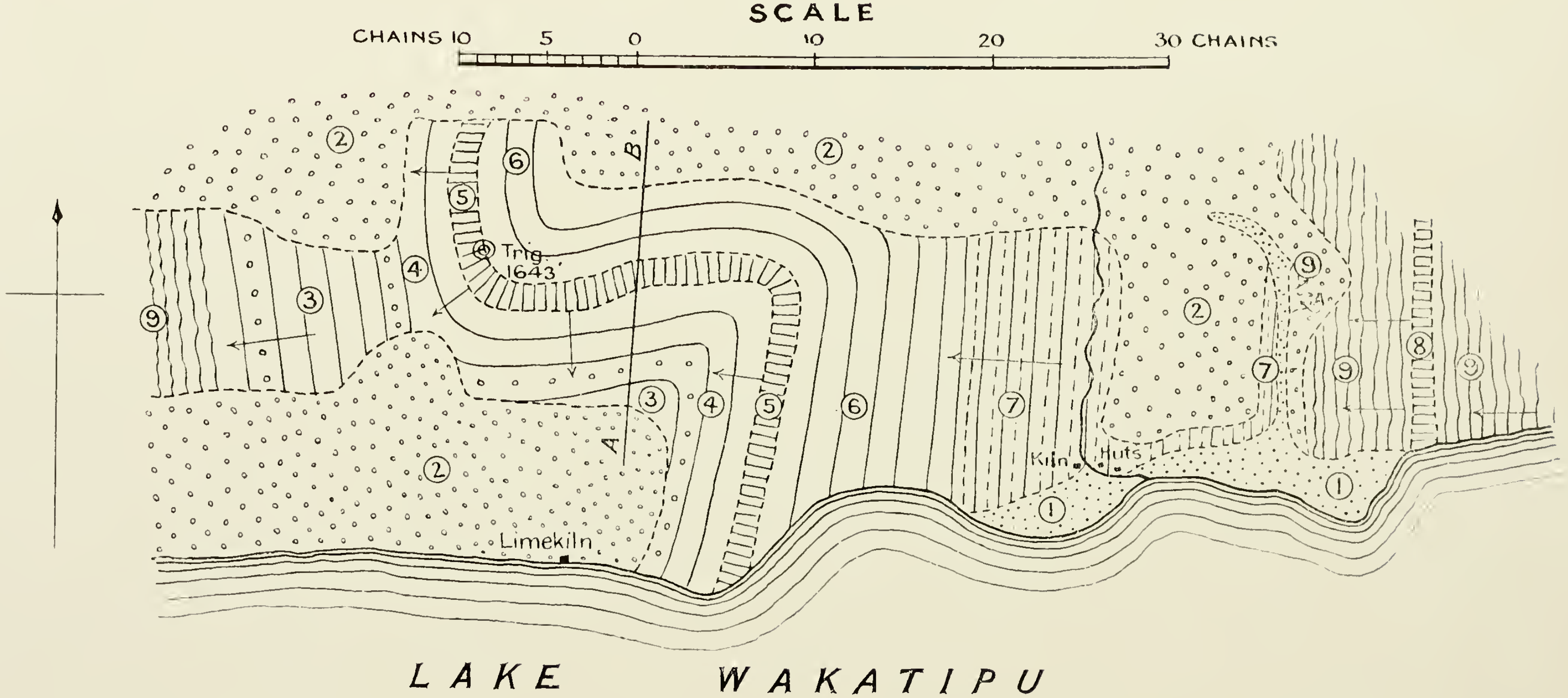
a. Silvery-grey mica-schist, not crushed. *b.* Mica-schist, crushed and contorted. *c.* Chlorite-schist, not crushed. *d.* Silvery-grey mica-schist. *e.* Outcrop of band of Tertiary sandstone and conglomerate, at 5,300 ft. above the sea, on the east slope of the Silverhorn.

The main significance of this narrow band of involved Tertiaries lies in the evidence it affords as to the age of the mountains of Western Otago. Here we have a portion of a marine littoral involved in a great crust-fold, and elevated to a height exceeding 5,000 ft. above the sea, affording the clearest proof that a sea-floor existed in the early Miocene where the Richardson Mountains now stand.

The constituent rocks and fossils of the Marine band are such as would be deposited on the shores of a rocky strand, and, as mentioned before, we find on examining the Bob's Cove section of the Oamaru Series that only the basement horizon is entangled among the schists. By what singular happening this has occurred is not quite easy to explain. The section exposed

PLATE XXVIII.

Geological Sketch Map of Bob's Cove



(1) RECENT: Beach Gravels and Tailings.
(2) PLEISTOCENE: Fluvio-glacial Drifts.
LOWER MIOCENE: (3) Sandstones and Conglomerates; (4) Sandstones; (5) Limestone; (6) Marly Sandstones; (7) Marly Clays and Marls; (8) Breccia-conglomerate entangled in Schists.
(9) PALÆOZIC: Mica-schist of Kakanui Series; (A) Striated Rock-surface.

 [To face p. 65.

along the shore of Lake Wakatipu, westward from the involved breccia-conglomerate, for a distance of 20 chains is shown in Fig. 16 below :—

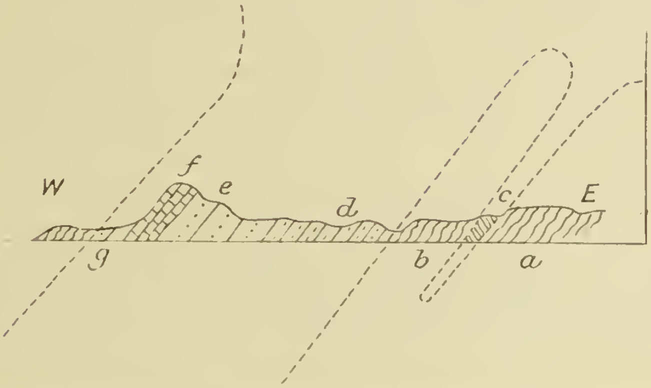


FIG. 16. SECTION FROM BOB'S COVE TOWARDS TWELVE-MILE CREEK, SHOWING INVOLVED MIOCENE TERTIARIES.

a. Mica-schist, crushed and brecciated. *b.* Mica-schist, soft and crumbling. *c.* Tertiary calcareous breccia-conglomerate, 65 ft. thick. *d.* Marly clays. *e.* Marly sandstones. *f.* Limestone. *g.* Sandstone and conglomerate.

The Warping of Tertiaries at Bob's Cove.

The limestone and associated beds abut against the shore of the lake. For the first 15 chains they strike a little to the east of north 5° (true), and dip west at an angle of 55°, the limestone forming the crest of the ridge. Beyond this distance they turn sharply to the west, bearing some 255° or 260° (true), the dip being now to the south at angles of 55° to 60°. The westerly course is followed until the trigonometrical station is reached, where the limestone and sandstones once more swing round to the northward, the dip being again westward at an angle of 60°. Seven chains north of the survey station the beds end quite abruptly, forming a steep escarpment facing northward.

This extraordinary warping of the Tertiary beds in a horizontal plane is shown in Plate XXVIII, facing this page. The section across the limestone ridge is represented in the next figure :—

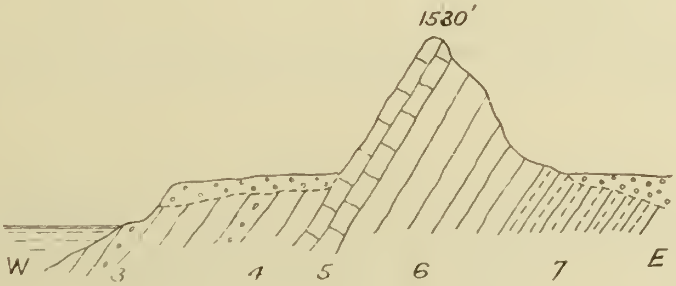


FIG. 17. SECTION ACROSS LIMESTONE RIDGE AT BOB'S COVE, LAKE WAKATIPU.

3. Sandstones and conglomerates. 4. Sandstones. 5. Limestone. 6. Marly sandstone. 7. Marls and marly clays.

The thickness of Tertiary beds exposed to view is probably somewhat over 1,500 ft., and we find that, while the basement bed has been deeply involved in an overturned fold of the schists, the greater part of the formation has been pushed back at right angles to the normal north-and-south course for a horizontal distance of some 17 chains, or 374 yards. The beds are simply bent, and show no signs of crush or faulting. At the end of 17 chains the beds are again bent at right angles, and then resume their northerly course.

The band of calcareous breccia-conglomerate that is entangled in the schists pursues an almost straight course towards Moonlight, and does not, so far as can be seen, partake of the warping of the upper members of the Marine Series. This would indicate that the uppei members were warped and twisted before the involvement took place along the Moonlight fold. But here we are met with the obvious difficulty that whatever warping affected the upper portion of the Marine beds should have also warped the lower, and of this there appears to be no evidence. If, on the other hand, the infolding of the breccia-conglomerate took place before the warping of the limestone and upper members of the same series, we should naturally expect that the movements or forces able to cause the distortion and warping of such a great formation should have also deformed the adjacent schists with their thin band of infolded strata.

The mechanics of the movement or movements which caused the warping are not easy to understand. All that we can be reasonably certain about is that the Tertiary limestone series before the warping ran north and south, and occupied a much greater linear extent of ground than at present, and that a tangential force acting from the north, or from the south, pushed and folded the strata back so as to be sharply bent at right angles at two places within a short distance of each other.

Thickness of Tertiary Beds.

It is not a little singular that the isolated patch of the Oamaru Series should show a thickness that is not often exceeded in other parts of New Zealand, even where the formation is very fully developed. The visible thickness is about 1,500 ft., being made up as follows :—

	Ft.
a. Sandstone and conglomerates, passing downward into bands of impure limestone	280
b. Pure limestone	50
c. Sandstones, marly and clayey	500
d. Marly clays	600
e. Calcareous breccia-conglomerate	65
Thickness exposed	1,495

The total thickness of the series is doubtless much greater than 1,495 ft., as the actual thickness of the upper sandstone and of the marly clays is not seen.

Fossil Contents.

The breccia-conglomerate of Bob's Cove is a limestone, in which so much broken schist in small angular pieces has been incorporated as to give the rock the appearance of a rough rubble concrete. In this brecciated rock there are numerous pieces of broken shells, but they are all so fragmentary that none of the genera to which they belong can be identified, with perhaps the exception of the genus *Ostrea*.

At Stony Creek the genera identified were *Venus*, *Pinna* *Ostrea Wullerstorfi*, *Turritella*, *Natica*, and *Dentalium*.

In the upper part of the marly clays at Bob's Cove were found a large *Cucullæa* that resembles *C. alta*, *Limopsis*, *Pecten*, *Natica*, *Dentalium*, and some corals. Most of these were also seen in the overlying marly greensands.

The limestone is composed mainly of comminuted shells and coralline structures. A small echinoderm is fairly abundant, but no example was found sufficiently well preserved to enable the genus to be determined. There is a band of sandstone near the base of the limestone, in which a small *Turritella* occurs in great abundance.

The sandstones and conglomerates overlying the limestone contain a few scattered casts of shells, but all of them that were seen were too indistinct for identification.

Age of Marine Series.

The general *facies* of the fossils is that of the Oamaru Series, but the evidence is not altogether satisfactory, the absence of *Pseudomussium Huttoni*, *Scalaria*, and other forms, that are elsewhere characteristic of that series, being somewhat puzzling. On the other hand, the presence of the large oyster, of *Cucullæa alta*, and *Dentalium Mantelli*, and the absence of any distinctively upper Secondary forms, favour the lower Miocene age ascribed to these beds.

Economic Value.

The marly clays near the base of the series, the limestone, and the overlying sandstone are all of great economic value. Their prospective value, and the uses to which they can be applied, and the prospects of finding coal in them will be discussed in the chapter devoted to "Economic Geology."

Pleistocene.

a. Terrace-gravels, old fans, and modified glacier-drifts.

b. Boulder-clays and moraines.

The great Mount Nicholas moraine, Queenstown moraine, and Miller's Flat moraine have already been described in Chapter III, dealing with "Glaciation," and need not be referred to at any great length here. They consist of tumbled deposits of sands, clays, and fluvio-glacial gravels, mingled with large masses of schist and greywacke. The fluvio-glacial gravels are mainly composed of greywacke pebbles and boulders that are foreign to the district, having been transported to the Queenstown and Arrow areas by the agency of glacier-ice.

The distribution of the greywacke gravels affords valuable evidence as to the direction of flow of the various streams of ice that were diverted from the main Wakatipu glacier.

One rock-laden stream of ice pushed its way far up the Twenty-five-mile Creek; two streams flowed into Moke Creek, one by way of Lake Dispute, the other by Lake Kilpatrick. Another stream, a small one, found its way through Arthur's Pass into the lower Shotover; while a great stream separated itself from the trunk glacier and flowed down the Kawarau Valley, its selvages spreading over the summit of Queenstown Hill and around the flanks of Bowen Peak.

The gravel terraces in the Shotover that have proved so rich in gold consist mainly of re-sorted fluvio-glacial material. Down to the mouth of Moonlight Creek the gravels of the Shotover consist entirely of schistose material, with occasional boulders of hornblende-lamprophyre, and of the fossiliferous marine conglomerates involved along the great Moonlight shear-plane, the only exception to this being the small boulder of granite found in Stevenson's Claim at the mouth of Skipper's Creek, to which reference has already been made.

Below the mouth of Moonlight Creek the Shotover gravels contain a sprinkling of greywacke material brought down by Moke Creek to Moonlight Creek. At Arthur's Point, and from there to the Kawarau River, the Shotover gravels contain a large proportion of greywacke, mainly derived from the sheet of boulder-clay that covers the surrounding ridges and downs.

At the time Lake Wakatipu was joined to Lake Hayes and occupied the greater part of the Arrow Flat, the Shotover ran at a higher level, and carried its load of material, mainly schistose, down to the upper end of Frankton Arm, in time forming what is now known as the Frankton Flat. A good section of this terrace, which is about 180 ft. high, is seen at the crossing of the Shotover on the road to Arrowtown.

It is noticeable that, while the surface of the terrace is almost level, the gravels composing it, besides showing current-bedding, are often arranged in rudely sorted layers that lie at an angle of 25° or 30° to the horizon, like the material thrown over the end of a miner's dump. From this we know that the Shotover discharged its load into the still waters of the lake, and as the process of reclamation progressed it carried its load further and further, the new material being continually tipped over the end of the advancing face of gravelly débris.

The Shotover also carried a large amount of fine sand and mud, which was borne still further into the lake—that is, nearer the present course of the Kawarau—before it finally subsided. The fine muds settled slowly in the still water, forming the thin-banded layers of silt and rock-flour we now see on the edge of the Frankton Terrace below the Kawarau Falls.

The saddle at Arthur's Point is occupied by greywacke gravel and patches of the Shotover schistose gravel, and here we have a good example, although on a small scale, of reverse drainage.

The Arthur's Point glacier flowed upward from Queenstown, and, crossing the saddle, joined the Shotover glacier, but it was drained by a stream that flowed in the reverse way—that is, towards Queenstown.

At the time of the retreat of the Shotover glacier the Shotover River ran at the level of the high terraces opposite Arthur's Point. The present deep channel or gutter in which the river runs had not then been excavated. That is a work of comparatively recent date. The Arthur's Point terraces are as high as the saddle, and it is almost certain that a portion of the Shotover River flowed across Arthur's Point Saddle to Queenstown, and continued to do so until the new channel to the Kawarau was cut so deep as to draw the whole of the drainage in that direction.

The contour of the ground, and the existence of the high terraces at Arthur's Point, led some of the pioneer gold-miners to think that perhaps the Shotover River at one time flowed across the saddle to Queenstown. But the great terrace forming Frankton Flat, the shallow channel and arrangement of gravels at Arthur's Point Saddle, prove that the main direction of the Shotover drainage was always towards the Kawarau, as it is now, and that only a small portion of that river at any time drained towards Queenstown.

Calcareous Ooze at Lake Hayes.

Reference has already been made to the thinly laminated muds and silts in the Frankton Terraces, on the side fronting the Kawarau River. Thin-bedded silts are also well seen below the Kawarau Falls ferry, and in the road-cuttings at the south end of Lake Hayes. At the latter place they are interlaminated with whitish-grey bands of a fine calcareous ooze, that, going eastward and westward from the outlet, become very pure, forming a deposit of considerable thickness.

This deposit of calcareous ooze, or soft incoherent limestone, is of great value for agricultural purposes, and already several hundred tons of it have been excavated and sent to Southland as a fertiliser.

This deposit, to which further reference will be made in the chapter on "Economic Geology," is a calcareous tuff, and doubtless owes its origin to the action of moss, rushes, and perhaps certain fresh-water algæ, in causing the precipitation of the carbonate of lime from the waters of the lake.

Character of Erratics.

Besides greywacke and greenstone tuffs, which are found in endless variety, there occur in the boulder-clays that are scattered over Queenstown Hill and Arrow Flat many varieties of crystalline rock, among which are hypersthene-diorite, augite-diorite, hornblende-diorite, norite, hornblende-syenite, and granite.

Dyke rocks are represented by hornblende-lamprophyres, some of which are related to the camptonite type. These are fairly common in the Shotover gravels. A large boulder of saxonite was found near Lake Johnson among the erratics of crystalline rock that are so abundant there, and a pebble of feldspar-porphyrite was discovered in the fluvio-glacial drift behind Queenstown Domain.

Among the holocrystalline granular basic rocks the norites are the most interesting. They are mostly dark-grey in colour, and coarse in texture, with a specific gravity ranging from 2·76 to 2·86.

Petrology of Crystalline and Igneous Rocks in Fluvio-glacial Drifts.

The crystalline and igneous rocks found in the fluvio-glacial drifts of the Clutha and Kawarau drainage-areas were collected and examined during the progress of the geological survey in the Alexandra, Dunstan, and Cromwell districts in the summers of 1905–6 and 1906–7. The same course has been pursued during the geological survey of the Shotover and Middle Wakatipu districts, the object steadily held in view being the tracing of these rocks to their source. The work of the past season, in the summer of 1907–8, has served to show that investigation will have to be pushed still further north and west before these much-travelled rocks are traced to the parent source.

No. SK III.—*Hornblende-lamprophyre.*—This is a black close-grained rock, fairly common in the high - level terrace drifts of the Shotover at Skipper's Point. Specific gravity, 2·96.

In thin slice, viewed under the microscope, it is seen to consist essentially of needles and prisms of hornblende, in a groundmass of idiomorphic brown hornblende and magnetite-dust.

Hornblende is the dominant constituent. It occurs in two generations—namely, as light-green prisms, and as long needles of a brown variety. The latter often taper at the ends, and are sometimes twinned parallel to the prismatic axis.

No feldspar is recognisable, and if present is certainly not idiomorphic.

Calcite is so abundant that the hand-specimen of the rock effervesces freely when hydrochloric acid is applied to it.

Magnetite is abundant in distinct grains, and as an exceedingly fine dust throughout the groundmass.

The calcite is probably a decomposition-product of a residual feldspathic base.

No. SK IV.—*Hornblende-lamprophyre.*—This rock occurs as pebbles in the Shotover and in the Queenstown moraine. It is black or blackish-brown, and very close-grained. Specific gravity, 2·96.

When examined under the microscope in thin section it is seen to consist mainly of pale-green prisms and long dark-brown lath-like prisms of hornblende, set in a groundmass of idiomorphic brown hornblende, magnetite, and what appears to be a glassy residue.

The hornblende is present in two generations—that is, in large, well-developed, pale-green or colourless prisms, and as the brown variety, which is strongly pleochroic, and occurs both as long lath-like prisms and as short needles, and stumpy well-formed crystals that crowd the groundmass.

Feldspar appears to be absent, or, if it forms part of the base, is not distinguishable. Apatite occurs in long thin needles, and magnetite, both as distinct grains and as a fine dust, is plentiful. Calcite is abundant.

The hornblende is the dominant coloured mineral in the rock, the dark-brown variety being the most abundant.

This rock is almost identical with No. SK III. It is related to the camptonite type of lamprophyre, but on account of the feldspar being indeterminate in the sections examined it has not been classed as such.

No. SK V.—*Hornblende-lamprophyre.*—This is a black to blackish-brown fine-grained rock. Specific gravity, 2·90.

In thin section the rock is seen to consist essentially of hornblende in two generations, with apatite as an accessory and calcite and magnetite as alteration-products.

The hornblende occurs sparingly as a pale green variety in well-developed prisms, and abundantly as the dark-brown variety in small, short, narrow prisms, generally with imperfect or corroded ends, and in stumpy well-formed idiomorphs that are often coffin-shaped. In some sections there are also a few long lath-like prisms of brown hornblende, similar to those seen in Nos. SK III and SK IV.

Magnetite is very abundant, mostly in distinct grains. Calcite, as a decomposition-product of the feldspathic base, is fairly abundant.

No. SK VI.—*Hornblende-lamprophyre.*—This rock occurs as pebbles in the Shotover gravels, and is also found near Frankton and at Queenstown moraine. It is close-grained, and almost black in colour, showing no phenocrysts to the unaided eye, but in places is speckled with white spots. Specific gravity, 3·02.

When viewed in thin slice under the microscope, the rock is seen to consist mainly of lath-like prisms of brown hornblende, with well-defined edges set in a pale bluish-grey feldspathic base.

Hornblende also occurs in small, broad, dark-brown idiomorphs with sharply defined terminations.

Idiomorphic feldspar is entirely absent, but the clear glassy residue is probably feldspathic. Apatite, in long thin needles, is common, and calcite, as an alteration-product, is abundant in some sections. Magnetite, in large irregular patches, but more often in small grains, is plentiful.

Saxonite (*Hartzbergite*).—This rock was found near Lake Johnson, as a boulder about 2 ft. in diameter. It is excessively tough, and has a dirty olive-green colour. Its specific gravity is 3·17. Decomposition is well advanced on the surface skin. The cataclastic structure so often seen in peridotite rocks is distinctly developed in this rock.

In thin slice, viewed under the microscope, the rock is seen to consist of olivine, with serpentinous matter and large plates of colourless enstatite.

The olivine occurs in grains and allotriomorphic crystals, that are much cracked and fissured, the crevices being occupied with serpentine. In fresh plates the birefringence is brilliant.

The enstatite occurs in broad colourless allotriomorphic plates, that often show a marked longitudinal striation which imparts a conspicuous fibrous or laminated appearance. Inclusions of calcite and serpentinous matter are abundant. Polarisation-colours are brilliant.

In the serpentinous matter there are irregular patches of magnetite and a little ferric oxide. There are also a few grains of an opaque brass-coloured mineral that is doubtless secondary pyrites. This rock probably came from the serpentine and olivine belt that extends as a more or less continuous line from the Caples River to the Red Hill, at the source of the Pyke River.

Saxonite, the hartzbergite of Rosenbusch, has been described from the Red Hill country by Professor Ulrich (Quart. Jour. Geol. Soc., xlvi, 1890, p. 627); boulders of hartzbergite, by Dr. Marshall, at Milford Sound (Trans. N.Z. Inst., vol. xxxvii, 1904, p. 483). Lherzolite, a rock closely related to saxonite, has been described by Dr. Marshall from the olivine country, at source of Hidden Falls Creek (Trans. N.Z. Inst. vol. xxxviii, p. 564).

No. M I.—*Norite* (*Hypersthene-gabbro*).—This is a dark-grey granitoid rock, found as a boulder in Scanlon's Gully, near Macetown. It is the only example in the Macetown district or upper Arrow Valley, and is undoubtedly an ice-borne erratic.

When examined under the microscope in thin slice the rock is seen to be holocrystalline, and to consist essentially of plagioclase and hypersthene, the former being the dominant constituent.

The plagioclase occurs in broad much-twinned plates, and in smaller crystals also well twinned. The large plates belong to a basic variety, and are probably labradorite. The smaller crystals may be anorthite. All are comparatively fresh.

The hypersthene is abundant in allotriomorphic crystals, faintly pleochroic, and sometimes altered to serpentinous matter, calcite, and magnetite.

Magnetite is abundant in grains and in interpenetrating threads.

A little biotite is present as an accessory.

No. J III.—*Norite.*—This is a dark-grey granitoid rock, with pale-pink feldspars. Specific gravity, 2·76. Found in glacial till near Lake Johnson.

When examined under the microscope in thin slice it is seen to be a holocrystalline aggregate of plagioclase and hypersthene, with a little accessory biotite.

The plagioclase occurs in large irregular plates, much twinned. It is of a basic type.

Hypersthene is very plentiful in allotriomorphic crystals; colour, pale; pleochroism, feeble; borders of crystals sometimes show alteration to chlorite.

Magnetite is abundant.

No. J V.—*Norite.*—This rock, like the last, occurs in large boulders in the glacial till covering the western slope of Ferry Hill, near Lake Johnson. It is a dark, granular, crystalline rock, with conspicuous flakes of biotite and pink feldspar.

In thin slice, it is found to consist essentially of plagioclase, hypersthene, and a brown mica, probably biotite.

The plagioclase is a basic variety. It occurs in tabular plates, polysynthetically twinned, and commonly not very fresh, and also in smaller idiomorphs, well twinned and fresh.

The hypersthene predominates. It occurs in allotriomorphic crystals and rounded grains; schiller structure is well developed; pleochroism fairly pronounced; alteration to a serpentinous product common.

Biotite is abundant, in irregular plates; pronounced pleochroism; often altered to chloritic mineral and magnetite.

Apatite occurs in large idiomorphic prisms and short broad forms. Magnetite is not abundant.

No. J I.—*Norite.*—A greyish granular rock, found near Lake Johnson, showing pink feldspars and a dark ferro-magnesian mineral. Specific gravity, 2·86.

In thin slice, under the microscope, is seen to be a holocrystalline aggregate of plagioclase and hypersthene.

The plagioclase is mostly fresh. It occurs in allotriomorphic crystals that exhibit pronounced twinning.

The hypersthene is common. It occurs in irregular plates; shows schiller structure, due to inclusion of magnetite along solution-planes.

Magnetite in separate grains is not abundant.

This rock is almost identical with No. J III.

No. A II.—*Hornblende-diorite.*—This occurs as pebbles and boulders in the gravels of Bush Creek, near Arrowtown. It is a dark-grey granitoid rock. Specific gravity, 2·89.

When examined in thin slice it is found to be a holocrystalline aggregate of plagioclase and hornblende, with biotite as an accessory.

The plagioclase is plentiful in irregular plates, well twinned, but often clouded by decomposition-products.

Hornblende is green, and very plentiful in allotriomorphic plates with resorption borders; pleochroism pronounced; shows signs of alteration to chloritoid mineral, with inclusions of magnetite sometimes twinned.

Biotite is present, but not abundant. Apatite occurs in long needles penetrating the feldspars. Magnetite is abundant, in irregular patches and in small grains.

No. J II.—*Hornblende-diorite.*—Found in glacial till near Lake Johnson. This is a fine-grained grey rock, with coarser granitoid segregations. Needle-shaped hornblende crystals can easily be distinguished by the unaided eye. Specific gravity, 2·69.

In thin slice the rock is seen to be holocrystalline, and to consist essentially of plagioclase and hornblende.

The plagioclase occurs in well-twinned plates, and is the dominant feldspar. A little orthoclase is present; commonly altered to kaolin and sericitic matter.

The hornblende is the green variety. It occurs in irregular plates; fairly abundant; shows alteration to chloritoid mineral.

Apatite is common, in long needles. Magnetite is very common as an alteration-product of the biotite.

No. Q I.—*Hornblende-diorite.*—This rock occurs as rounded pebbles in the Queenstown moraine. It is a dark-grey granitoid rock. Specific gravity, 2·92.

In thin slice it is seen to be a holocrystalline aggregate of feldspar and hornblende, with a little accessory biotite.

The feldspar is mainly plagioclase, which occurs in two generations—namely, in large irregular plates, much twinned, but clouded by alteration-products, and small irregular crystals, commonly quite fresh, with few inclusions.

The hornblende is the green variety; abundant in large crystals; often much altered to chloritoid matter, with numerous inclusions of magnetite.

The biotite occurs in irregular plates. Apatite is common, in needle-shaped prisms. Magnetite is plentiful.

No. Q III.—*Hornblende-syenite.*—This is a dark-grey fairly fine-grained rock, found in Queenstown moraine, showing thin needle-shaped crystals of hornblende. Specific gravity, 2·79.

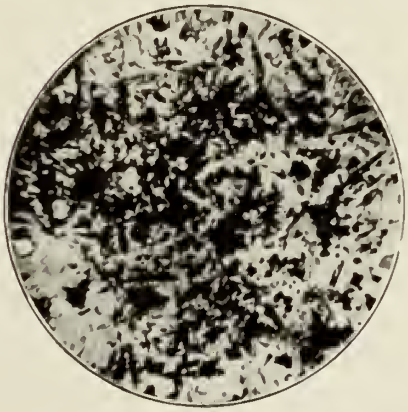
In thin slice it is a holocrystalline aggregate of feldspar and hornblende, with accessory biotite.

The dominant feldspar is orthoclase, which is commonly much altered and clouded by sericitic matter. Twinning is seldom seen.

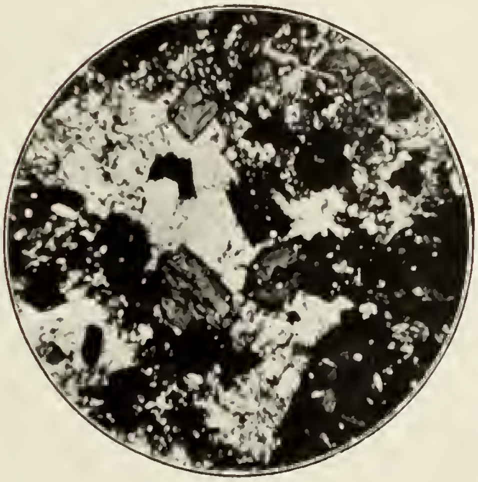
PLATE XXIX.

1.

2.



3.



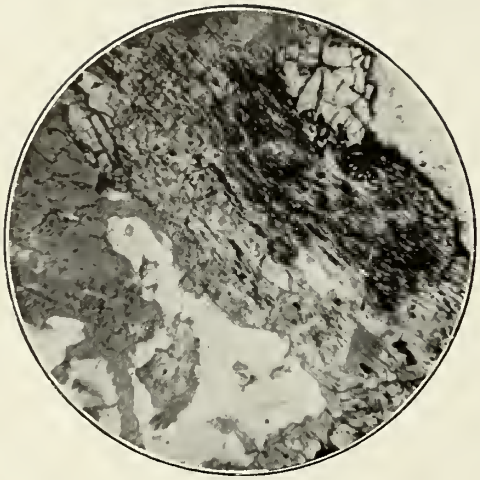
4

1. Hornblende-lamprophyre (Camptonite Type).
2. Hornblende-lamprophyre.
3. Hornblende-lamprophyre (Camptonite Type).
4. Hornblende-lamprophyre.

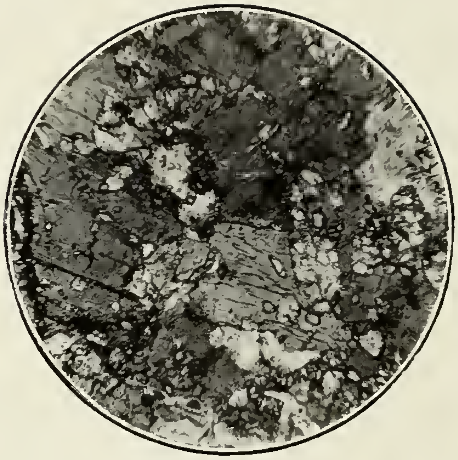
Magnified 30 times.

Nos. 1 and 3 photo James Park.] *[Nos. 2 and 4 photo H. Hamilton.*

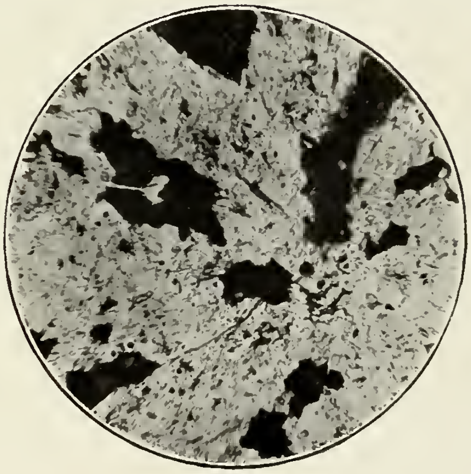
PLATE XXX.



1.



2.



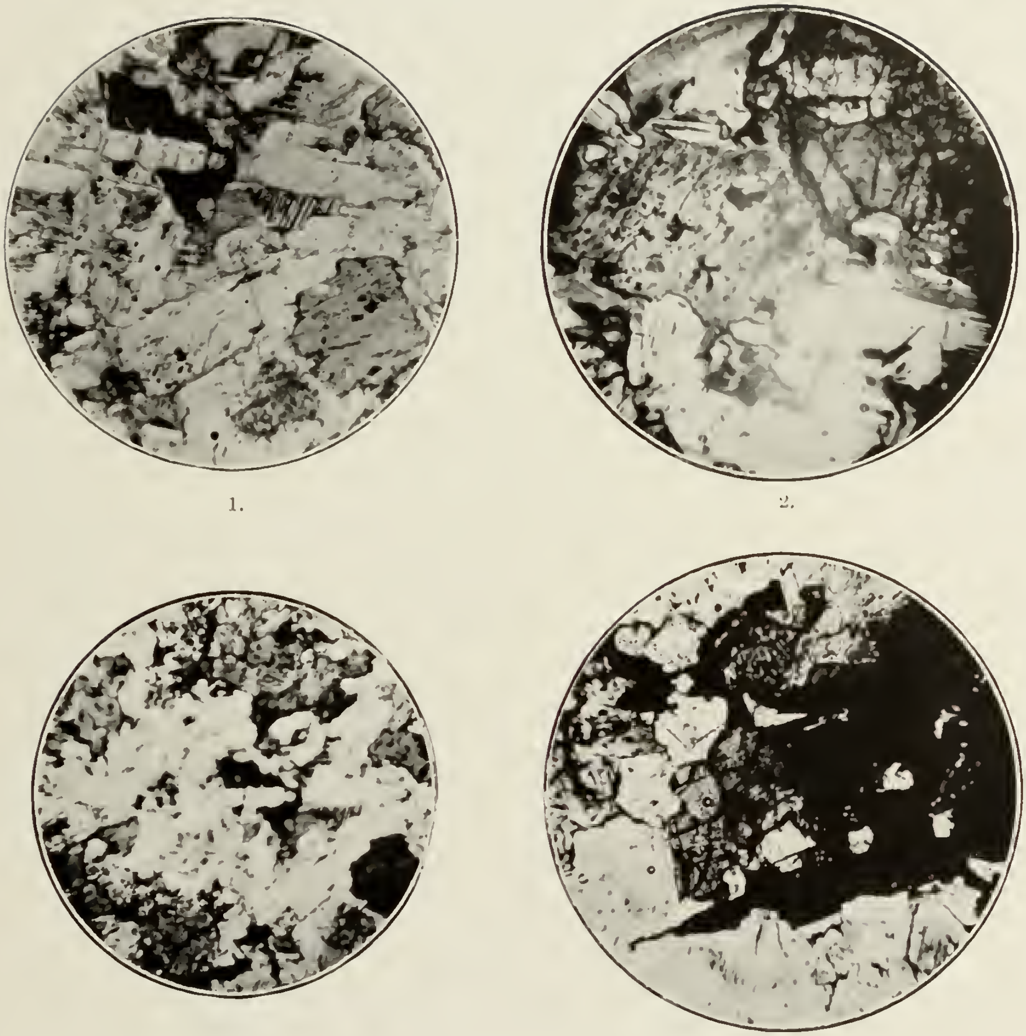
3.

1, 2, 3. GRANITE.

Magnified 30 times.

Photo H. Hamilton.]

PLATE XXXI.



1 and 2. Norite.
3. Hornblende-syenite.
4. Hornblende-diorite.

Magnified 30 times.

No. 1 photo H. Hamilton.] *[Nos. 2, 3, and 4 photo James Park.*

The hornblende is green, and occurs in allotriomorphic plates; commonly much altered. Strongly pleochroic.

Biotite is not common. Quartz occurs in small bunches. Apatite and zircon are present. Magnetite is fairly abundant, in irregular grains.

No. Q IV.—*Hornblende-syenite.*—This is an even-grained granitoid rock, showing phenocrysts of feldspar and hornblende, and a little pyrites.

Under the microscope it is seen to be a holocrystalline aggregate of orthoclase and hornblende.

The orthoclase occurs in large irregular plates, rendered almost opaque in places with alteration-products. The twinning is obscured by the kaolinization.

The hornblende is green; in irregular plates; decomposing to chlorite and magnetite.

Pyrite is not abundant; occurs as small cubes. Zircon is common. Magnetite is plentiful as an alteration-product of the hornblende.

No. SK I.—*Granite.*—A small boulder in Stevenson's Sluicing Claim at Skipper's Point; apparently an erratic. It is a light-coloured crystalline aggregate of feldspar, biotite, and quartz.

The orthoclase is not abundant. It occurs in small idiomorphic plates, with well-marked binary twinning; shows alteration to kaolin and calcite along borders.

The biotite is completely altered to chlorite, which is in places stained brown with iron-peroxide. Quartz is the chief constituent of the rock, in large irregular crystals sometimes containing inclusions.

Sphene, zircon, and apatite are common. Magnetite is fairly plentiful. Calcite is present, but not abundant.

No. J IV.—*Granite.*—From a boulder in glacial till near Lake Johnson. It is an even-grained rock showing quartz, feldspar, and dark mica.

The feldspar is mainly orthoclase and oligoclase, the former commonly much kaolinized, the sericitic inclusions being symmetrically arranged.

The biotite occurs in irregular plates that are often altered to chloritoid matter and magnetite.

The quartz occurs in small interstitial grains, but is not abundant. Apatite is plentiful, in long needles. Sphene and magnetite are present, but not at all common.

Recent.

River-beds, Alluvial Flats, Swamps, &c.

The contours of the country are so steep, and the valleys so narrow, that the area included under this heading is comparatively insignificant. The river-bed gravels are largely a rewash of the gold-bearing fluvio-glacial drifts forming the high terraces perched on the sides of the valleys, and, like them, have proved a valuable source of wealth. The beds of the main and lateral streams formed natural sludge-channels, in which for countless ages the gold, released from gold-bearing veins in the adjacent mountains and gathered from the re-sorting of the terrace-gravels, became concentrated, as in the sluice-box of the present-day miner.

CHAPTER VII.

ECONOMIC GEOLOGY.

Introduction.

The minerals and metals that have proved of economic importance in this district are gold and scheelite ; among those that may be turned to commercial account are the calcareous tuff or limestone at Lake Hayes, the limestone at Bob's Cove, and the marl at the same place. Among the minerals that may be looked for with a reasonable hope of success are coal, copper, and perhaps antimony.

Quartz-mining.

Economic Possibilities.

The lodes of Macetown and Skipper's occur in the same zone of mica-schist, and belong to the same type of replacement lode, as the reefs at Bendigo and Carrick Range in the Cromwell district. The lodes at Bendigo alone have yielded gold to the value of some three-quarters of a million sterling. The Premier and Tipperary mines, at Macetown, and the Phœnix Mine, at Bullendale, have produced a large amount of gold ; while we have still before us the Shotover Consolidated, that through various vicissitudes and adverse circumstances has been a going concern for nearly thirty years.

The bulk of the gold produced in Otago in the past has been derived from alluvial sources, but the time is approaching when renewed attention will have to be directed to quartz-mining if the annual output is to be maintained. Gold-bearing lodes occur in nearly every gully and gorge in the Arrow, Macetown, Shotover, and Skipper's districts. In some places they are numerous. Many have been prospected at the outcrop by local companies and individual prospectors; but numbers exist that have not been touched or tested in any way. Description of some of these last will be found in the following pages.

Many of the lodes are small, and perhaps the majority low-grade; but low-grade ventures have often proved the most profitable, their successful working being dependent on two main and all-important factors—namely, adequate development in advance, and economy in working-costs.

The Alaska-Treadwell Gold Mine, in Douglas Island, Alaska, is an object-lesson in the profitable working of low-grade ore. This mine has paid millions of pounds in dividends from a free-milling ore that has yielded gold to the value of only 12s. per ton—the working-costs amounting to some 8s. or 9s. per ton. At Bendigo, in Victoria, 3 dwt. and 4 dwt. ore is easily worked at a profit, even in deep mines. But we have no need to go abroad for an example of cheap mining. We have one at our door. Mr. Waters, consulting engineer for the Shotover Consolidated, near Skipper's Point, has informed the author that the total costs for mining, milling, and management at that mine amount to only 12s. per ton, which is a noteworthy result when we consider the high rate of wages, the scarcity and consequent high cost of mine-timber, and the heavy freight-charges on all mine-supplies.

Capable and economical management is the keynote of successful mining, for in a low-grade venture the profits may in a manner be said to come out of the savings.

What can be done at one mine can be done elsewhere, and with costs brought down to 3 dwt. of gold per ton there is warrant for the belief that quartz-mining is still in its infancy in Otago.

In the district under review systematic prospecting ought to be carried on along the Sunrise and Premier-Tipperary lines of lode at Macetown; on the lodes discovered by the Geological Survey in the Arrow Gorge near Arrowtown, more especially on the ridges between the Arrow River and Coronet Creek, and between the Arrow River and head of Bracken's Gully; and at Bullendale and Skipper's Point. The lodes that have already been worked should be searched for the continuation of the pay-shoots of ore that were worked in the upper levels, and new lodes should be prospected in a thorough manner for shoots of profitable ore.

Gold-mining is still an industry of paramount importance to Otago and to the Dominion. It stands unique amongst the world's industries, in that its production is not a perishable or consumable commodity, but one that increases the currency and gold reserve, thereby stimulating industrial enterprise in many directions. As a matter of good policy it should be fostered by every legitimate means in the power of the people and State.

Gold-bearing Lodes.

Summary of Characteristics.

A close investigation of the Macetown, Skipper's, and Shotover lodes shows that they belong to the class of *replacement lodes*, in which a zone of country rock lying between two more or less parallel fissures has become crushed by wall-movement and more or less replaced by quartz, which is commonly gold-bearing.

It may be of interest to state that the lodes of the Bendigo and Carrick Range goldfields, that proved so productive for many years, belong to this group of fissure-lode.

The chief characteristics of these replacement lodes, which will probably be found to belong to a type of ore-deposit more common than is supposed, are as follows:—

(1.) They lie between two more or less parallel fissures, enclosing between them a zone of country rock, which is always more or less crushed and shattered.

(2.) They traverse the country rock independently of the planes of bedding or foliation.

(3.) The enclosed zone of country rock has been crushed and shattered by the pressure exerted by faulting and wall-movement.

(4.) The crushed rock is more or less silicified and replaced by quartz.

(5.) The extent of the replacement varies in different lodes, and even in the same lode the replacement may be partial in one place and complete in another.

(6.) The lode-matter often presents a brecciated appearance, due to the cementation of the broken rock by silica.

(7.) In cases of partial replacement the crushed rock is commonly replaced by vein-quartz deposited on one or both walls; but the vein-quartz may lie in any part of the crushed rock, forming irregular lenticular masses that may pass from wall to wall.

(8.) In cases where replacement is more complete the veins on the opposite walls unite, thus forming a solid ore-body, enclosing between them a *horse* of country rock.

In the majority of the lodes the bulk of the lode-filling is crushed rock, forming what is locally termed *mullock*, hence the name *mullock-lode* often applied to them.

Gold-bearing Lodes in Macetown District.

There are numerous gold-bearing lodes within the watershed of the Arrow River. They vary from a few inches up to many feet wide, and all contain gold in greater or less quantity.

The Macetown lodes have so far proved the most productive. They occur in two distinct systems—namely, the Tipperary system, which runs from Scanlon's Gully to Sawyer's Creek, where it is known as the Premier line of lodes; and the Sunrise system, that crops out on Advance Peak at an altitude of some 5,000 ft. above the sea. Of these the Tipperary-Premier line of lodes has been the richest. It is enclosed in a comparatively soft, grey, silky mica-schist. It comprises four distinct lodes, all more or less parallel, and situated in the zone of mica-schist that lies on the upper or hanging-wall side of the strong bands of chlorite-schist that cross near the mouth of Scanlon's Gully.

The Sunrise line of lodes is enclosed in a mica-schist that is somewhat more flaggy. It lies to the north of the Premier lodes.

At the time of the author's visit to Macetown the Premier Mine had been closed down for some years, and for this reason there was no opportunity for an inspection or examination of the lodes that had been worked.

According to Mr. Henry A. Gordon,* the Premier section was worked from an incline adit 2,000 ft. long, with a grade of 1 in 4, from an intermediate level 180 ft. above, and from another level below the adit. The gold occurred in shoots of quartz, the remainder of the lode being filled with crushed country rock.

For the following information relating to the Macetown lodes the author is indebted to Mr. L. O. Beal, M.A.Inst.M.E., mining engineer, who has been at different times connected with the development of many of these mines:—

"The Macetown reefs are fissure-veins with well-defined walls, carrying in many places a great thickness of pug. The hanging-wall of the reefs is the more defined and regular.

'The stone is of a very free-milling nature, sometimes carrying a little and sometimes a good deal of pyrites, some of which is arsenical. The gold is of high grade, being worth from about £3 18s. to £3 19s. per ounce. It is readily visible in the stone, and much of it is coarse in character. The pyrites is sometimes barren, and sometimes contains a good deal of fine gold.

* Papers and Reports Relating to Minerals and Mining, 1897, p. 120.

" The tendency of the lodes is to come together in depth. In many places there are from two to four reefs running parallel with each other, with occasional loops, carrying in some parts a large body of quartz ; in other parts, horses of mullock.

" The mullock occasionally carries small veins or stringers of quartz of considerable richness.

" The underlie of the lodes is towards the south-west, their general direction being 310° (true). They contain between the walls shoots of quartz alternating with rubbly mullock and mullock with small veins or stringers of quartz. Occasionally there are small veins of quartz running from the walls into the country rock.

" The shoots of quartz dip to the north-west at angles varying from about 25° to 75°, the average being about 40°.

" One shoot of quartz containing rich stone was worked down from the surface through the Gladstone and Premier quartz claims to a depth of 3,300 ft. from the outcrop. At that depth the working-expenses were so heavy, mainly for maintenance and timbering, that further following of the shoot at greater depth was abandoned.

" This shoot was worked first from the surface, then by adits, and finally by a dip-drive on the floor of the shoot.

" The lodes as a rule do not contain any considerable quantity of water, which is seldom over 30 to 50 gallons per minute.

" The mountains being very precipitous, there is every facility for mining by driving adits. In some places half a mile of driving would give 2,000 ft. of backs. Great facilities are afforded also for the use of self-acting aerial tramways to get the quartz down economically and transport the timber to the mine for maintaining the levels and securing the stopes.

" The stopes in some of the lodes required face-boards and struts (or toms), and in others the walls and contiguous country-rock are so solid that an odd strut and face-board is sufficient.

" The stopes are generally taken out in 7 ft. benches, and filled in again with mullock or country-rock to prevent subsidence, and so maintain the stability of the workings.

" Water-power is plentiful for working the batteries by means of water-wheels.

" There are about eight main lines of lode, besides several smaller ones. The lode-formation varies from a foot or two up to 30 ft. or 40 ft. in width.

" The most extensively worked lodes are the Premier and Tipperary mines. Next in order come the Gladstone, Homeward Bound, All Nations, Victor Emmanuel, Maryborough, Garibaldi, Sunrise, Golden Treasure, Balsh's, Hamilton and O'Neill's, and Anderson's.

" As may be imagined, there are a good many dislocations of the shoots of gold, occasioned by small faults and slides, and also by veins coming in from the walls.

" The old mine-surveys being in most cases insufficient, and seldom accompanied with proper longitudinal and cross-sections of the lodes and workings, the run of the pay-shoot of gold has often been lost. The fact of there being often two, three, or even four lodes coming together on the underlie, and all maintaining their individual walls, has made the shoots of gold difficult to follow without the guidance of an experienced mining engineer to supervise, survey, and keep the mining operations in proper order.

" The average underlie of the lodes is from 50° to 80°, the direction of dip being south-west. In a few places they are vertical."

The present claims carrying on mining operations are Farrell's Mines, Hamilton and O'Neill's, and Anderson's. With a heating plant in the battery-building crushing can be carried on in most places right through the year, except in winters of unusual severity.

Warden Stratford reports that the reefs at Macetown were first tested about the year 1876. According to Mr. McIntosh,* three lines of reef were first worked—namely, (1) the Homeward Bound line, (2) the Maryborough, and (3) the Advance Peak line.

* Robert McIntosh, A.O.S.M. " Quartz-mining," " The New Zealand Mining Handbook," 1906, p. 151.

The Homeward Bound line was opened in 1876 by Messrs. Raven and Barclay, who won 551 oz. of gold from 542 tons of stone while opening up. On the same line, to the north-west, were situated the Lady Fayre, Gladstone, MacKay's, and the Premier claims.

The Defiance line of lode runs parallel to the Homeward Bound, and on the east side.

The Maryborough was opened up in February, 1876, and from 5 tons of stone crushed from a foot-wall leader, 23·5 oz. of gold was obtained. On this line were situated the leases of the Garibaldi Company, Duke of Wellington No. 2 South, Victor Emmanuel No. 3 South, and Finn's Lease No. 4.

Mr. McIntosh continues his interesting sketch in the following terms :—

" The All Nations line is parallel to the Maryborough, about 5 chains to the southward. From a leader between these two lines 345 tons of quartz yielded 39 oz. of gold. The Tipperary, Geraldine, and Caledonian leases were continuations of the All Nations line, while the Canton and Ancient Briton claims were branches trending south.

" With regard to the Main Lode line, there appear to be three parallel lodes here trending north-west. Several rich leaders radiate from these lodes, as high as 5 oz. of gold per ton having been obtained from them. The Katherine was a rich leader from the north-east lode of this parallel. Development-work was carried on, and in 1878 a public crushing plant was erected and quartz crushed from various reefs. Some of these parcels, which were said to be well representative of the quartz in the mines, gave rich yields. Eighty tons of quartz from the Gladstone Mine yielded 304 oz. of retorted gold ; 50 tons from the Tipperary yielded 127 oz. For some time the stone from the Tipperary Mine yielded nearly 1 oz. 8 dwt. of gold per ton.

" It would be impossible in this short sketch to detail the history of this district during the next few years. Numerous leases were taken up, but operations were not successful in all cases. Capital was required, as the district for some years was only provided with a pack-track. In 1884 the main road from Arrowtown was opened for traffic.

" Warden Hawkins, reporting in 1886, says, ' Of all the numerous gold-mining companies that were called into existence on the discovery of payable quartz at Macetown only two remain, of which the Premier Mine has been the most successful.'

" During 1886 the Sunrise Lease Gold-mining Company struck good stone, and was the only mine at work during 1888 and 1889. In the latter year an endeavour was made to float a company on the London market to work the Premier and Tipperary mines. This flotation was completed, and British capital was introduced into the district in 1890. About this time prospects became brighter. The Sunrise struck good stone, and erected a new battery. Unfortunately, in 1891 expectations were not realised. Poor results were obtained from the Sunrise and Premier mines, while operations were not commenced at the Tipperary Mine. During 1892 the Sunrise Company sold its plant and claim to the Premier Consolidated Company, which carried on continuous operations during the year for a return of 945 oz. of gold from 957 tons of quartz crushed.

" The Tipperary Company was re-formed in London in 1892, with an available capital of £10,000, so that in this mine, as also in the Premier, development-work was carried on during 1893. In that year the Premier Company crushed 3,163 tons of quartz for a yield of 1,985 oz. The Glenrock Consolidated Company purchased the Premier and Sunrise mines in 1895, and preparations were made to work these properties on a more extensive scale.

" The Tipperary Gold-mines Company was reconstructed in 1896, and a new company, called the ' Westralia and New Zealand Gold-explorers (Limited),' took possession of the property. Work was continued along the usual lines for the next few years.

" In 1898 several well-known mines—the Victor Emmanuel, Morning Star, Black Angel, Garibaldi, Maryborough, Homeward Bound, Lady Fayre, and Golden Treasure—were consolidated into one holding as ' Farrell's Consolidated Mines.' The intention was to place these properties on the London market. Operations in the Tipperary and Sunrise mines were not very successful, and the mines were closed down in 1899; but the Premier continued to be worked, 2,825 tons of quartz being treated for a yield of 1,661 oz. of gold during the year 1899. The Indian Glenrock (Wynaad) Company continued operations in the Premier Mine during 1902, in which year 2,178 tons of quartz yielded 1,752 oz. of gold.

"In 1903 the Premier-Sunrise (New Zealand) Gold-mining Company purchased the Premier Mine from the Indian Glenrock Company. The mine was worked continuously during the year, with fair results.

"Work was resumed in the Tipperary Mine in 1903, but, as the further development of the mine included the installation of expensive machinery, operations have since been at a standstill.

"The Premier-Sunrise Company continued operations during 1904 and 1905. In the latter year the available stone was stoped out, and considerable prospecting failed to open up a new ore-body."

Sunrise Mine.—This mine is situated near the summit of Advance Peak, at an altitude of some 5,000 ft. above the sea. The mine has been closed down for some years, and all that can now be seen is the surface outcrop along the narrow ridge behind Advance Peak.

The ground has been prospected by shallow trenches along the outcrop and by a low-level drive. The lode as it appears on the surface consists of irregular blocks of compact quartz, generally rust-brown in colour, and separated from each other by stretches of crushed country rock.

The quartz has proved rich in some places and worthless in others. Mr. Gordon reports that a sample of 30 lb. yielded, by amalgamation, gold at the rate of 11 oz. per ton. On the other hand, 4 tons of ore yielded only 1 oz. 3 dwt. of gold.

The lode is one that may yet be proved to contain a valuable shoot of pay-ore, but prospecting at an elevation of 5,000 ft. is seriously handicapped by the severity of the winter, the ground being covered with snow from June till November.

Mr. Stanford, the general manager of the Glenrock Consolidated (Limited), the proprietors of the Sunrise property, reporting on the work done on the Sunrise lode during 1898, stated that a considerable amount of prospecting-work had been done by means of crosscuts to prospect the adjacent country. The crosscuts proved the existence of two lodes, running apart, both carrying gold wherever they were struck, but not in payable quantity. The workings were very close to the outcrop, and the whole country was found to be much broken and disturbed.

The former proprietors of the property, the Sunrise Lease Gold-mining Company (Limited), succeeded in extracting 1,207 tons of quartz from the mine, which yielded in the mill 1,018 oz. of gold, valued at £3,909.

All the creek-beds below this mine have been sluiced for payable returns, and much of the gold obtained in the ripples was found to contain adhering particles of quartz.

Tipperary Mine.—This mine, to which reference is made by Mr. McIntosh, has now been closed down for some eight years. It is situated in Scanlon's Gully, about two miles and a half from Macetown. When in operation it was worked by surface stopes, drives, and a shaft. A low-level crosscut 1,953 ft. long was put in at a point in the gully three-quarters of a mile below the mine, but where the lode was cut it was not payable. The lode was then driven on for a distance of 490 ft.—namely, 270 ft. westward and 220 ft. eastward. It was found to average about 4 ft. wide, and to underlie south-west at an angle of 68°, but unfortunately no payable ore was found at that depth.

Killarney Line of Lode.—This is parallel to the last, and about 1,000 ft. to the westward. Little work has been done on it, except a little surface prospecting.

Dublin Lode.—This lode strikes 310° (true), and stands nearly vertical. It is at present being worked by two levels from the surface, and a rise. Its width varies from 18 in. to 4 ft. The lode-matter consists of crushed and broken schist, through which there run a few small veins of quartz. The ore is crushed in a stamper-battery, and yields from 6 dwt. to 16 dwt. of gold per ton. The mine is at present being successfully worked by Messrs. Hamilton and O'Neill, who have displayed much energy in opening up the ground.

Anderson's Lode.—This lies about 500 ft. east of the Dublin line of lode. Its bearing-course is 329° (true)—that is, about north-north-west—and it stands nearly vertical. It varies from a mere thread or clay-parting to 30 in. wide. The mica-schist in which it is enclosed strikes about north-and-south, and dips west at an angle of 48°.

The lode-matter consists of a zone of crushed and slickensided schist, traversed with veins of quartz that are gold-bearing. The prospects are at present very promising, and a small battery is being erected on the east bank of the Goldburn, near the mouth of Scanlon's Gully, for the purpose of crushing the ore and extracting the gold. This battery should also prove useful for the treatment of trial parcels of ore from other mines in the neighbourhood.

Sylvia Lode.—This crops out on the north side of Bush Creek, at the first forks. Its course is 305° (true), and it dips to the south-west at an angle of 78°. It has been opened up by a low-level drive at the old battery level and several surface levels from Branch Creek, some 600 ft. higher up the slope of the range.

The lode-matter consists of crushed mica-schist and veins of quartz lying between two more or less parallel fractures. It varies from 6 in. to 4·5 ft. wide, and most of the quartz lies on the hanging-wall side. The walls are sharply defined.

The sectional view of the lode, and its relationship to the enclosing mica-schist, is shown in the next figure :—

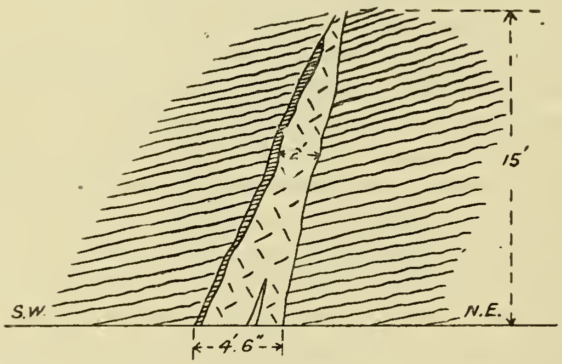


FIG. 18. SECTIONAL VIEW OF SYLVIA LODE, BUSH CREEK, MACETOWN DISTRICT.

The vein of quartz lying on the hanging-wall varies from 4 in. to 8 in. thick. On the floor there appears, as shown in the above figure, the apex of another small vein that will probably increase in width in going down.

This lode has the same bearing and characteristics as the lodes in the Tipperary-Premier system, to which it doubtless belongs ; but whether it should be correlated with the Premier, Lady Fayre, Homeward Bound, or Maryborough lode is a point not easily determined.

Arrow Lodes.

In passing up the Arrow Gorge towards Macetown, the silvery-grey mica-schist is found to be traversed by a number of lodes and veins of quartz, almost all of which were found, on examination at the outcrop, to contain gold varying in amount from a few grains to several pennyweights per ton. Of these the Alpha, Gamma, Delta, Iota, Zeta, and Lambda lodes, hereinafter described, are new discoveries made by the Geological Survey during the progress of the field-work. They all lie in a zone of schist half a mile wide, and are more or less parallel

SUMMIT OF MOUNT AURUM, FROM WEST SIDE.

Photo Miles Aspinall.]

ADVANCE PEAK, NEAR MACETOWN.

Photo James Park.]

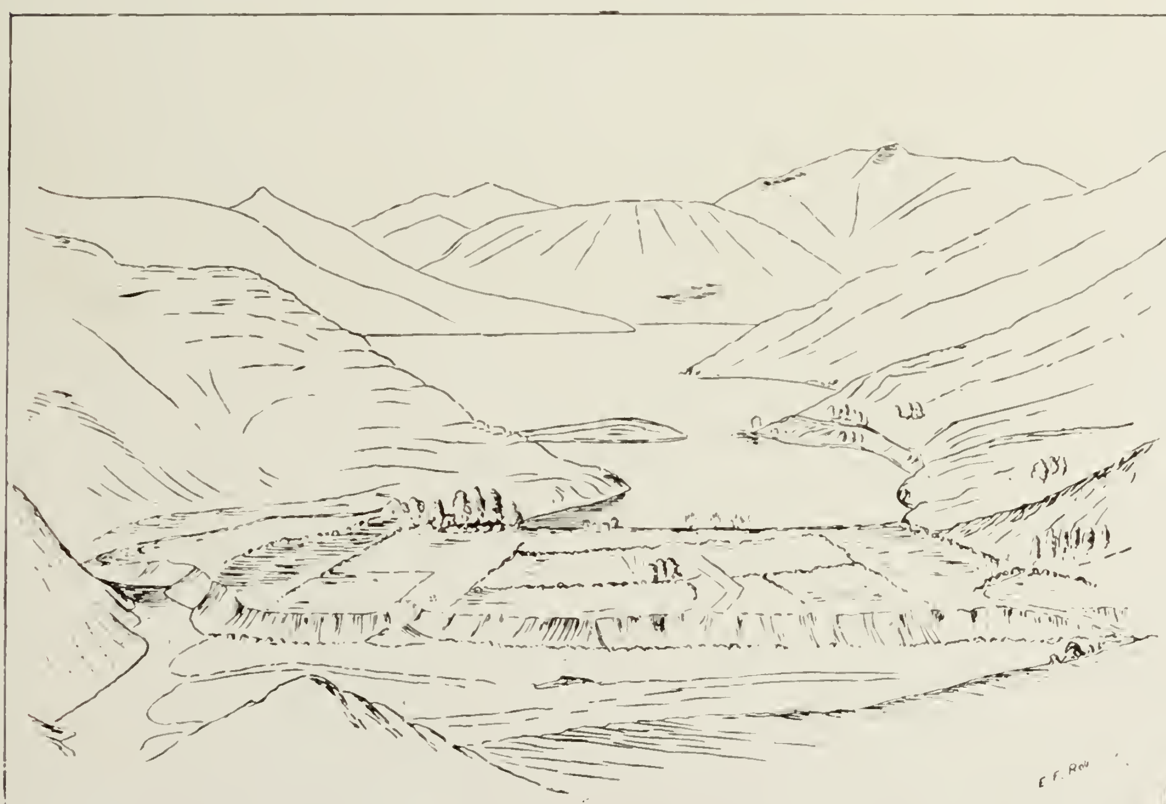
PLATE XXXIII.

SKIPPER'S POINT BRIDGE AND GOLD-WORKINGS, SHOTOVER RIVER.

Photo Miles Aspinall.]

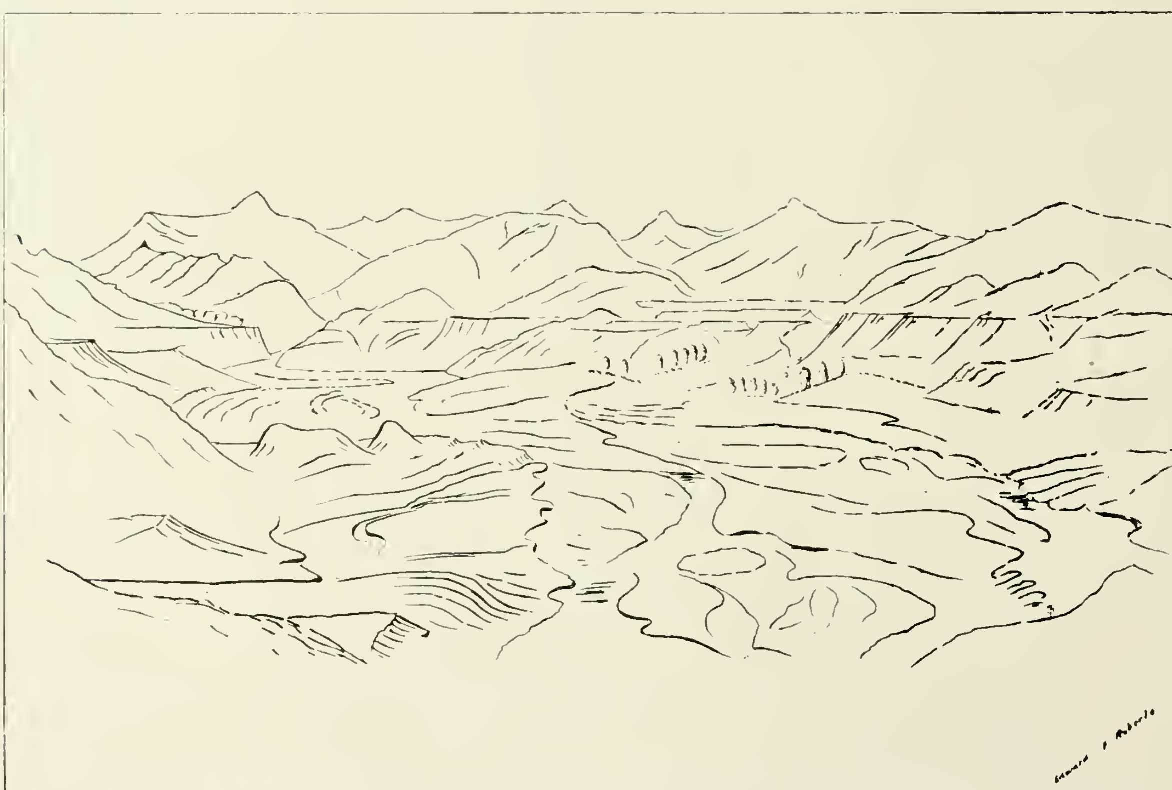
PLATE XXXIV.

Upper Shotover Valley.



Lake Wakatipu, with the Dome of Mount Nicholas in the Distance

Mount Aurum, looking up Skipper's Creek.



Shotover Valley.

to each other. They have the same relationship to the chloritic-schist bands as the Tipperary-Premier lodes, of which the author is inclined to think they are the southerly continuation. They all contain gold, and are well worth careful and systematic investigation.

Alpha Lode.—This is a well-defined vein of quartz that crops out on the side of the Macetown Road, about 5 chains above the junction of the Arrow River and Bush Creek. Its strike is about 307° (true)—that is, nearly parallel with the Premier lodes—and it stands about vertical, there being only a perceptible inclination to the westward.

The vein-matter consists of compact grey crystalline quartz, varying from 2 in. to 5 in. wide. A sample of the ore was found by fire assay to contain gold at the rate of 1·5 dwt. per ton.

The Alpha lode does not appear to have been known till now. It is well-defined, and contains promising-looking stone. By examining and prospecting it along the outcrop it is quite possible that a shoot of payable ore may be located somewhere along its course. The sectional view of the lode is shown in the following figure :—

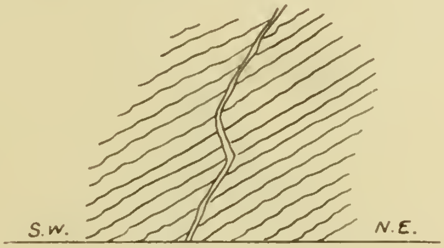


Fig. 19. Cross-section of Alpha Lode, near Arrowtown.

Gamma Lode.—This is found cropping out in the gorge of the Arrow, about 15 chains below the junction of First Creek and 10 chains above the old mining-camp half a mile from Arrowtown.

The lode strikes about 303° (true), and stands practically vertical. It varies from 1 ft. to 5 ft. or 6 ft. wide, and consists of crushed mica-schist and quartz veins lying between well-defined walls. As seen at the outcrop in the face of the cliff, the quartz is found to vary from a mere thread to 8 in. wide. It occurs as two distinct veins, one on each wall, but uniting in going upward.

The irregular character of the walls and the disposition of the veins of quartz are shown in the next figure :—

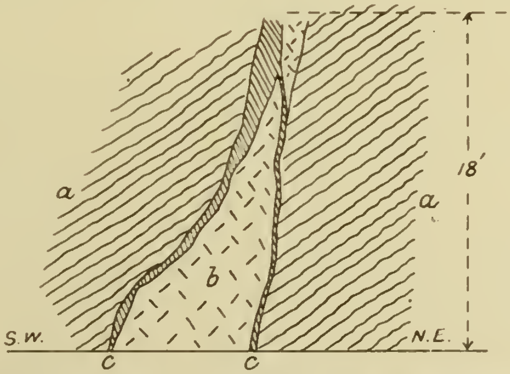


Fig. 20. Cross-section of Gamma Lode, near Arrowtown.
a. Mica-schist. *b.* Crushed schist. *c.* Quartz veins.

Samples of the quartz in this lode when subjected to fire assay were found to contain gold at the rate of 1 dwt. 18 gr. and 2 dwt. 8 gr. per ton.

The quartz veins vary from a thread to a foot thick, and, although not payable at the outcrop facing the Arrow River, may be found to contain payable ore at some place along the course of the lode.

The Gamma lode is a new discovery, and should be systematically prospected by trenches at various points. Its course is almost parallel with that of the Alpha lode, described above.

Delta Lode.—This was discovered cropping out some 80 ft. east of Gamma lode. It is a narrow vein of quartz, varying from a clay parting to 6 in. wide. Its strike is 312° (true), and it dips to the south-west at very high angles, commonly about 80°. The foot-wall is very clearly defined.

A sample of the quartz from this lode gave a return of 1 dwt. 12 gr. of gold to the ton.

Iota Lode.—This lode crops out on the bank of the Arrow River about 40 ft. east of Delta lode, which has just been described. It consists of two narrow branching veinlets of quartz, varying from 1 in. to 4 in. wide, enclosing between them a zone of crushed schist.

The sectional view of these veins, as seen in the face of the river-cliff, is shown in the next figure :—

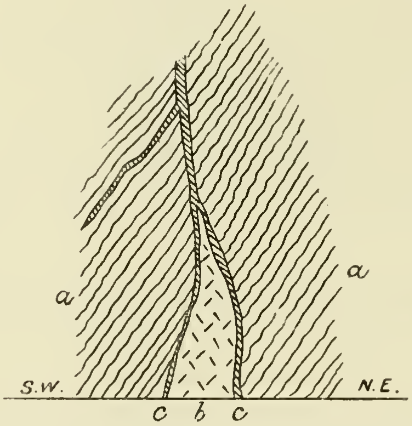


Fig. 21. Cross-section of Iota Lode, Arrow Gorge, near Arrowtown.
a. Mica-schist. *b.* Crushed schist. *c.* Quartz veins.

The width between the walls of the lode at the level of the datum-line in the above figure, which is water-level, is 4 ft. 6 in. A sample selected from the eastern leg was found to contain gold at the rate of 1 dwt. 18 gr. per ton.

Zeta Lode.—This is a small lode that crops out at the north end of the deep road-cutting opposite the mouth of First Creek. It strikes 325° (true), and stands practically vertical. It varies from 12 in. to 24 in. wide between the walls, which are sharply defined.

A fair sample selected from the whole height of the exposure facing the Arrow River was found by fire assay to contain gold at the rate of 3 dwt. 4 gr. per ton.

Lambda Lode.—This crops out on the bank of the Arrow, some 4 chains further east than the Zeta lode. It strikes about 318° (true), and is quite vertical or in places inclines slightly to the westward. The enclosing rock of this and of the lodes already described is a soft, crumbling, flaggy mica-schist with silvery-grey lustre. The dip is everywhere westward, at angles varying from 40° to 65°. In the vicinity of this lode the angle of dip is 42°.

The lode-matter consists of a compact body of yellowish-brown quartz, varying from 6 in. to 18 in. wide. A sample was found to contain gold at the rate of 2 dwt. 18 gr. per ton.

The Pyritic Lode.—This crops out near the head of Shadrach Creek, at a height of over 2,000 ft. above the sea and 600 ft. above the bed of the Arrow River. Its course is about 35° (true)—that is, parallel with the upper part of the stream, in the bed of which it is exposed at several points. It stands vertical, and can be traced through a height of 200 ft.

The lode has been opened up by trenches and surface drives, and, from what can be seen in these, it has a width varying from 1 ft. to 5 ft. The lode-matter consists of crushed mica-schist, containing a vein of hard, pyritic, brecciated quartz, from 6 in. to 18 in. wide, lying on the western wall.

About 250 ft. below the crown of the hill it throws off a branch lode, consisting at the surface of dark-red rubbly clays that contain irregular masses of hard, pyritic, brecciated quartz.

A sample of the pyritic ore when submitted to assay was found to contain 2 dwt. of gold and 2·5 dwt. of silver per ton.

The sectional view of this lode, as seen in the bed of the stream, is as is shown in the next figure :—

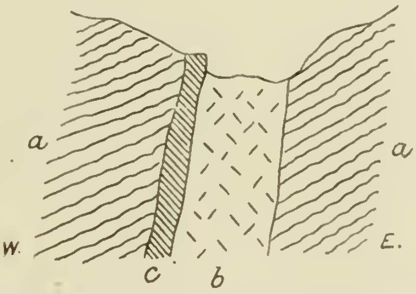


FIG. 22. CROSS-SECTION OF PYRITIC LODE, SHADRACH CREEK, ARROW GORGE.
a. Mica-schist. *b.* Crushed schist. *c.* Pyritic quartz.

Criterion Lode.—This lode crops out on the bank of the Arrow River, near Arrowtown. Its course, as seen by the direction of the old workings, is about 315° (true), and it stands vertical or inclines slightly to the eastward. The old mine has been so long abandoned that little can now be gleaned by an examination of the surface. The following particulars of the lode and of the operations of the old company were furnished to Professor Ulrich in 1874 by Mr. H. J. Cope,* and will be read with interest by miners of the present day :—

" The reef was discovered in 1864 by a Victorian quartz-miner, and is the one first opened in the province. It consists of a clayey mica-schist mullock, enclosing veins and bunches of quartz. Besides being worked for a good length from the surface, a shaft was sunk on it to a depth of 120 ft., from which it was worked out from 90 ft. down, up to the surface, and 70 ft. in length. There was not much water coming in at the bottom of this deep shaft. Another shaft was sunk on the reef at the south-east end of the open workings, about 40 ft. deep, and it was followed from this for 80 ft. in length.

" In the main workings it was at first taken out from 1 ft. to 4 ft. in width, but another manager subsequently broke into what has been considered the foot-wall, and worked several feet of it, which paid nearly as well as what had been previously taken. A leader was found joining the reef which also contained good gold. The yields from the crushings ranged at first from ½ oz to 1½ oz. of gold per ton—average about 1 oz.—but gradually fell off to ½ oz., which would not pay at the time, and the mine was therefore given up. The gold was

* " Report on the Geology and Goldfields of Otago," F. W. Hutton and G. H. F. Ulrich, 1875, p. 221.

nowhere completely lost in the workings; but the best seemed to occur in a shoot dipping westward in strike.

"The company had a small battery of five heads of stamps, with a common amalgamating-table and blanket-strakes in front, the whole poorly constructed. Much difficulty was experienced in clearing the boxes on account of the mullock being of a very clayey nature, and all accounts agree that a great deal of the fine gold was lost. The management was altogether very bad, for it took about twenty men to keep the small battery going.

"The shares of the company were at one time at a very high premium, and the coming-to-grief of the mine subsequently has been the principal cause of destroying confidence in quartz-mining in the district, and that prevented the latter from being properly prospected since. Considering all the different points relating to the auriferous character of the reef, the workings, management, &c., in concluding, I cannot help coming to the conclusion that the reef certainly deserves another trial, and that this, if effected in an economic and systematic manner, and with the use of good machinery, might likely prove a very profitable speculation."

Cornish Lode.—This outcrops on the edge of the Crown Terrace, about a mile eastward of Arrowtown. It is a well-defined lode, varying from 2 ft. to 5 ft. wide. The lode-matter consists of crushed schist and irregular veins of compact, bluish-grey, pyritic quartz. The course of the lode appears to be 335° (true), and the dip south-west at an angle of 85°. Intermittent attempts to work this lode have been made at various times during the past thirty years, but without success.

Columbia Lode.—This occurs about 20 chains higher up the gully, near the top of the Crown Terrace. Its strike is about 340° (true), and it stands practically vertical. It varies from 6 ft. to 8 ft. wide, consisting mainly of quartz in which gold can be seen in places. In the early seventies it was opened up along the outcrop by a trench nearly 40 ft. long, but no payable stone was disclosed.

Bullendale Lodes.

Achilles Mine (Old Phœnix).—This mine is situated some seven miles from Skipper's Point. At the time of the geological survey of the district no work was being carried on at the mine, and, as the old workings and incline shaft were full of water and inaccessible, no information as to the lodes or methods of working could be gathered by personal examination.

For the following particulars concerning the mine and gold-returns the author is indebted to an article on "Quartz-mining," contributed to the "New Zealand Mining Handbook." 1906:—

"The Phœnix Mine was originally prospected about the year 1862, when it was purchased by Messrs. Bullen Bros., who are said to have expended £50,000 in developing the property. During the early stages of development some good returns were obtained, but the work undertaken was mainly of a prospecting and opening-up nature, and the mine did not become a paying concern until about the year 1884. It was recorded that from February, 1884, to November, 1885, 6,400 oz. of gold was taken from the mine, the total yield up to 1887 being about 15,500 oz. In 1888 a poor block of stone was being worked, the yield being as low as 3 dwt. per ton, and this continued during 1889, when the owners purchased the Phœnix Extended. In 1891, 4,835 tons of quartz was crushed for a return of 3,197 oz. of gold. The property was floated on the London market in 1892, and the new proprietary took possession on the 31st March, 1893. During 1892, 5,457 tons yielded 1,920 oz. of gold; all the quartz was taken from the Phœnix Extended section.

"Operations were continued by the new company, called the 'Achilles Gold-mining Company,' and good returns were obtained from time to time. In 1896 the quartz in the lode then being worked averaged $1\frac{1}{2}$ oz. to the ton, and since the date of registration, in 1893, 7,181 oz. of gold has been produced, valued at £27,500. The mine continued to be worked until 1901, but not with the success attending its former operations. Owing to the capital of the company being then exhausted, and no payable stone in sight, the mine was permanently closed down in May, 1901.

"The property was purchased in 1903 by the Mount Aurum Gold-mining Company, and operations were resumed in 1904 on the British-American line of reef. An aerial tramway connects the mine with the battery. The deep workings have not been unwatered."

Mr. Henry A. Gordon, F.G.S., in his annual report to the Mines Department for 1896, writes as follows :—

"*Achilles Mine* (Area, 125 acres).—This mine is situated at Bullendale, near the head of Skipper's Creek, on the western slopes of Mount Aurum, from which emerge the richest gold-bearing streams in New Zealand. From the bottom of the shaft, which is 150 ft. deep, starts No. 2 level, with which the lower levels are connected by a perfectly true grade. Up this grade the quartz is hauled in trucks by an engine worked by compressed air, the trucks containing 5 cwt. each, and is sent to the surface, where it is emptied into self-delivering paddocks, whence it goes in trucks holding 25 cwt. to the battery, where all the fine stuff is sifted out on grizzlies, the coarse lumps being reduced by rock-breakers ; thence it passes into automatic feeders, which pay the quartz, now reduced to a uniform size, into the mortar-boxes. The automatic feeders have now been in use for twenty-five years, and have given perfect satisfaction. Thus the quartz is conveyed from the face of the mine where it was first broken out to the battery without being handled oftener than at the initial filling into the first trucks.

"At No. 2 level the lines of lodes have converged so much that they are only 105 ft. apart, so that the work of looking for any missing portion is reduced to one-half of what it was at the low-level adit, 120 ft. above No. 2 level. Now, to carry out the argument : At No. 4 level, 184 ft. below No. 2 level, the distance is only 68 ft. between the converging lodes, and in place of the middle lode, which has so far not been located at this level, there is a body of phyllitic rock that carries payable gold for a distance that has not yet been correctly defined. If the three lines of lodes continue to converge at the same ratio they will unite at a level about 90 ft. below No. 5 level.

"The present exploitations in the Achilles Mine are chiefly confined to No. 5 level, and are of so encouraging a nature that the chief energies of the management and plant are directed to their development. As stated, this level has reached the depth of 1,200 ft. below the highest outcrop of the lode on the hill sideling above it. It is connected by two winzes 160 ft. apart with No. 2 level, which in its turn is connected with the surface by the present vertical working-shaft 150 ft. deep. A grade already spoken of leads down from No. 2 to No. 5 level, and is fitted with a double line of rails for the ascending and descending trucks. These connections provide the most perfect ventilation that could be desired, as well as all the other necessary conveniences of access, so that it may be pronounced to be in full working-order. The two winzes are in course of being connected. The stone now being attacked had a width of 7 ft. at No. 4 level ; but at a depth of 83 ft.—that is, at No. 5 level—it had widened out to 13 ft., the whole of which is sent to the mill. The new shaft, when completed, will be 600 ft. deep from the surface to the bottom of the mine, and will give every convenience in the future working of the mine. It will be 12 ft. by 4 ft., divided into three compartments of 4 ft. by 4 ft. each in the clear.

"The Achilles stone has been pretty free from pyrites so far, but as greater depths are reached they are increasing in quantity, and may be found to be impregnated with gold when still greater depths are reached. The new race from the left-hand branch of Skipper's Creek will give 400 ft. of pressure, and will be applied directly, instead of employing it for the purpose of generating electric power, as is done at present. The new race is nearing completion, and is expected to be available for motive power before winter. It will have the effect of very considerably reducing the working-expenses, and will insure a greater degree of efficiency in the work done. The race will be applied to a Pelton wheel, and the present air-compressor at the shaft may be done away with. Hauling and pumping will then be directly done from the mouth of the shaft. The electric power will be held in reserve for the extremes of weather and other emergencies. The Achilles Goldfields Company was registered in 1893, and up to the present date 7,181 oz. of gold has been produced, valued at £27,500. Out of the time of its existence there must be deducted eight months during which repairs were carried on. During the year 5,453 tons of stone was crushed, giving a return by amalgamation of 4,413 oz. Seventy men were employed."

Skipper's Point and Shotover Lodes.

Shotover Consolidated Mine.—This is the only mine at which active operations are being carried on at the present time in the Skipper's district. It was first opened about 1867 by the Nugget Company, and worked without much success until 1884, when it was let on tribute. For some twelve years afterwards the ground was owned and worked by the Gallant Tipperary Company, which went into liquidation, the property being sold to the Shotover Quartz-mining Company (No Liability), which commenced operations on the 1st January, 1898. In 1906 the mine was assigned to the present company, which has met with a fair amount of success.

In the first twenty-five years gold to the value of £48,000 was obtained from ore won in various parts of the property, being at the rate of 13 dwt. per ton.

The mine is situated on the west bank of the Shotover River, about two miles from Skipper's Point. It is traversed by two main lodes, locally known as the Eastern and Western lodes respectively.

The *Eastern* lode crops out about 2 chains below the junction of Nugget Creek, and can be traced along the surface for a distance of some 1,900 ft. to a point where it joins the *Western* lode. Its course is 325° (true), and it dips south-west at an angle of 68°.

The lode-matter varies from 15 ft. to 70 ft. wide, and consists mainly of crushed mica-schist traversed by veins of quartz, which open out in places to more or less lenticular masses. The quartz lenses are not often met with, only four having been found at the machine level in a distance of 1,900 ft. of driving.

The first lens occurs about 700 ft. from the mouth of the level; the second at 1,100 ft.; the third at 1,380 ft.; and the fourth at 1,640 ft.

The first lens was 20 ft. long and 12 ft. high; the second 40 ft. long and about the same in height; and the third about 70 ft. long, 170 ft. high, and from 0 ft. to 15 ft. wide; and the fourth, which is being worked at the present time, 25 ft. long, about 50 ft. high, and 25 ft. wide. The third lens yielded gold to the value of some £7,000. Up to the end of May, 1908, 992 tons of ore from the fourth lens yielded 319 oz. 18 dwt. 6 gr. of gold.

At the time of the author's visit, a distance of 250 ft. had been driven beyond the fourth lens without finding another body of quartz. But the existence of four lenses at the machine level warrants the belief that other ore-bodies will be found, not only further ahead, but also underfoot.

The lode was worked along the outcrop by an old company in the seventies, with a fair measure of success.

The *Western* lode crops out at the level of the Shotover, some 215 ft. further down the bank. It strikes 336° (true), and dips south-west at angles varying from 65° to 70°. The lode-matter consists of crushed and silicified schist, intersected with veins of solid bluish-grey quartz.

The lode can be traced on the surface in a westerly direction from the bank of the Shotover to its junction with the Eastern lode, a distance of 1,900 ft. Beyond the junction, the united lodes, following the course of the Eastern lode, which is the stronger of the two, are traceable a further distance of 1,800 ft. up to the boundary of the company's lease, and even beyond that, over the crest of the ridge overlooking Skipper's Creek. The work on this lode consists mostly of surface levels and stopes, the work of former owners of the ground.

Going south-eastward, both the Eastern and Western lodes can be traced for a considerable distance up the flank of the range, up to a point near the sources of Deadman Gully.

For much of the information recorded above, the author is indebted to the courtesy of Mr. T. Otto Bishop, A.O.S.M., the mine-manager.

Mr. D. B. Waters, A.O.S.M., consulting engineer to the company, has kindly placed at my disposal the following interesting excerpts from a report he furnished on the mine in 1906, dealing chiefly with the operations of the Shotover Quartz-mining Company, the former owners :—

"The mine has been in existence for thirty years, the different sections being held by different parties, ultimately, however, becoming amalgamated and known as the 'Gallant Tipperary Mine.'

"The Gallant Tipperary Company carried on operations for many years, driving the main and intermediate levels, and stoping the ore opened up above these levels. This company had practically worked out all the ore opened up, and were driving the intermediate level ahead, when operations were stopped owing to the closing of the Colonial Bank, which had advanced some money to the company. The property, consisting of claim, battery, and water-rights, thus fell into the hands of the Colonial Bank, was put up to auction, and bought in by some of the old Gallant Tipperary shareholders.

"These shareholders eventually decided to form a new company, to be known as the 'Shotover Quartz-mining Company (No Liability).' This company was formed in March, 1898, with a nominal capital of £6,000, in 24,000 shares of 5s. each. Out of these shares, 12,000 shares paid up to 2s. 6d. per share, representing a value of £1,500, were allotted to the vendors to recoup them for purchase of the property from the Colonial Bank, and other expenses incurred, and as full payment for the claim, rights, and plant. The remaining 12,000 shares were issued to the public, and were fully applied for, the vendors themselves taking 6,700 shares.

"This flotation thus gave the company the sum of £4,500 as a working capital, the whole of which was eventually obtained by calls, no shares being forfeited.

"From the time the Colonial Bank took over the mine, and operations ceased, some two years elapsed before the new owners started operations again. During that time much of the main level fell in, rendering a considerable expenditure necessary to reopen the old mine. After due consideration the new owners decided to open up the mine afresh at a lower level, so as to tap the ore previously worked lower down. To do this it was decided to drive what is known as the 'machine level,' this level starting 277 ft. lower than the main level, and, as shown, just level with the roof of the battery-house.

"The reef-formation in which the ore-bodies occur crosses the Shotover River nearly at right angles, running N. 40° W., with a dip of 70° to the south-west. Hence it will be seen that all the levels are driven on the reef-formation, and are continually prospecting the lode-formation.

"When the Shotover Company started operations it was expected, from surface indications, that a considerable amount of barren ground would have to be passed through—in fact, that 1,000 ft. to 1,200 ft. at least would have to be driven before any ore could be expected in bulk.

" The driving of the machine level was started in March, 1898, and steadily prosecuted. After driving about 750 ft. a small block of gold-bearing ore gave 34 oz. of gold from 108 tons. Driving was continued, and after two years of steady work with four men a distance of 1,020 ft. was reached, whilst prospecting rises and crosscuts amounted to 256 ft. more. The level was timbered throughout, and always kept in good repair, the work being done at an average cost of £1 15s. per foot.

" Driving was still continued, and between 1,100 ft. and 1,200 ft. another small block of ore was struck, which only yielded 280 tons of ore, from which 101 oz. of gold was obtained.

" When the level reached 1,316 ft. a much larger block was struck, which continued for a distance of 70 ft., and from this block a considerable amount of ore has now been mined. This block has gone up a distance of some 200 ft. above the level, but after a height of about 150 ft. was reached the value of the stone became much poorer.

" The machine level was continued some little distance further—to 1,450 ft.—at which point it now stands (1906).

" The mine is equipped with a 10-head stamper-battery, which was erected at a cost of £950 in 1903, and, so far as crushing and amalgamating is concerned, it has given every satisfaction.

" Besides this, expenditure was incurred in connection with the water-races and in erection of a small cyanide plant, &c., as shown hereafter under details of expenditure.

' The following table shows revenue up to the 15th October, 1905 :—

	£	s.	d.
Cash from first issue of shares	4,500	0	0
Cash from second issue of shares	1,245	0	0
Debenture-issue	750	0	0
Bullion sold	7,443	1	2
Rent of water	362	8	4
	14,300	9	6

" From the 15th October up to the 31st December, 1905, the amount of gold obtained had a value of £70 2s. 7d., giving a total revenue to the 31st December, 1905, of £14,370 12s. 1d.

" *Summary.*—The Shotover Quartz-mining Company spent a total sum of £14,775 17s. 9d. up to the 31st December, 1905, whilst the revenue from all sources amounted to £14,370 12s. 1d. The expenditure is as follows :—

	£	s.	d.
Capital expenditure at mine	5,726	18	2
Office expenses	1,664	11	7
Mining and milling	7,384	8	0
	14,775	17	9

" Gold to the value of £7,513 3s. 9d. was won from about 5,000 tons of ore."

Peat's Lode.—This lode crops out on the north side of the Shotover, on the steep face overlooking the river, at a point about a mile from the Shotover Consolidated Mine. It strikes 75° (true), and dips southward at an angle of 60°.

The outcrop has been prospected for a considerable length by shallow holes and open cuts or trenches. In these workings the lode-matter is seen to consist of crushed mica-schist veined with small strings of rusty-coloured quartz, in which colours of gold are seen in places.

At one point a prospecting-hole has been sunk to a depth of 9 ft., and in this case the cross-section of the lode is as shown in the next figure :—

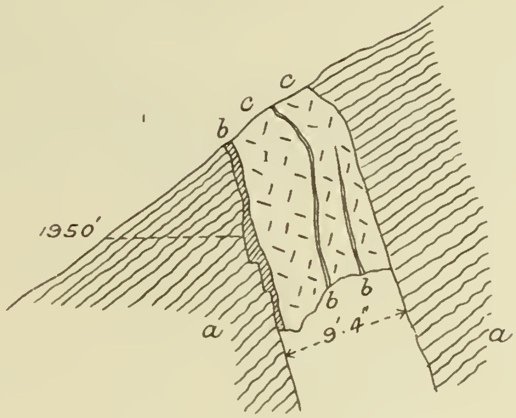


FIG. 23. CROSS-SECTION OF PEAT'S LODE, IN PROSPECTING-HOLE, SHOTOVER RIVER.
a. Mica-schist. *b.* Quartz veins. *c.* Crushed schist.

The hanging-wall is smooth and often slickensided. The foot-wall is not so clearly defined, and is not quite parallel to the opposite wall.

The veins of quartz in the main prospecting-hole are small, being not often over a few inches thick. As shown in Fig. 23, the foot-wall vein is the largest, and it is said to be the richest.

Some 10 ft. south of the prospecting-hole, in the first trench going westward on the course of the lode, the quartz veins widen out to 12 in. or 16 in., the crushed and broken schist having decreased proportionately.

In the next cutting going westward, some 20 ft. distant from the last, the lode is bent over and crushed along the outcrop, the curvature having been caused by the pressure of the ice-sheet that sculptured the adjacent slopes in the glacial period. In this cutting the width of the lode is some 6 ft., most of the solid quartz being confined to the hanging-wall side, where it shows, on the north face, a thickness of 20 in.

It is the intention of the owners of the ground to prospect the lode further by driving a crosscut from the slope below in such a position as to give about 80 ft. of backs on the lode where it is intersected. The outcrop prospects seem to warrant the cost of such an undertaking. The lode is situated in such a way with respect to the surface-contours that its development could be carried on by a moderate outlay of capital should the prospects found at the proposed level justify such a course.

Junction Lode No. 1.—At a point about 40 chains from the Shotover junction there crops out on both sides of Skipper's Creek a strong quartz lode that strikes a little to the east of north, and dips easterly at angles varying from 70° to 80°. It varies from 2 in. to 24 in. wide, as seen along the outcrop, and can be traced in a northerly direction along the steep slopes of the ridge on the north side of Skipper's Creek for a distance of 15 chains, and in a southerly direction towards Stevenson's Claim, at Skipper's Point, for some 5 chains.

Some 20 yards below the bridle-track leading to the Shotover Consolidated Mine the lode throws off a branch to the westward. This branch vein strikes 332° (true), and stands nearly vertical. It varies from 2 in. to 12 in. thick, and lies between well-defined walls.

The main lode consists of hard grey quartz, with a shining vitreous lustre, that encloses irregular masses of broken silicified schist. The ore, so far as can be judged by an examination of the surface outcrop, is comparatively free from metallic sulphides. The walls are everywhere sharply defined, and in a few places exhibit smooth slickensided faces.

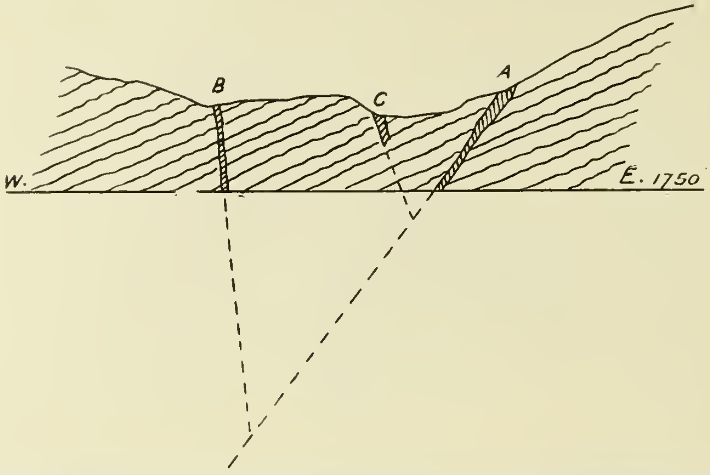


FIG. 24. DIAGRAMMATIC SECTION SHOWING RELATIONSHIP OF JUNCTION LODES, SKIPPER'S POINT.
A. Main lode. B. Branch vein. C. Second branch vein.

About 35 ft. west of the main lode, at the level of the track, there is another outcrop of quartz, marked C in Fig. 24. It varies from 2 in. to 16 in. thick, and consists of bluish-grey quartz. Its relationship to the main lode cannot be determined, on account of the covering of slope-débris, but it seems not improbable that it will unite with the main lode in depth, as also will the branch vein marked B.

The enclosing country rock is a crumbling silvery-grey mica-schist, consisting of thin laminæ of quartz and micaceous matter. It strikes a little to the east of north, and dips westerly at angles between 12° and 20°. On the hanging-wall side of the main lode, and some 100 ft. above it in stratigraphical position, the mica-schist is intercalated with a distinct bed of chloritic mica-schist about 12 ft. thick.

A sample of ore selected from the outcrop of the main lode, at the point where it crosses the bridle-track, showed on assay a value of 2 dwt. 12 gr. per ton.

Junction Lode No. 2.—This lode crops out about 3 chains east of No. 1—that is, it lies between No. 1 lode and the mouth of Skipper's Creek. It crosses Skipper's Creek, and can be seen on both banks as a strong well-defined body of ore. Its strike varies from 345° to 350° (true), and it stands vertical or bends in a peculiar way to the westward. Going southward it passes into Stevenson's alluvial claim.

The lode-matter consists of compact, grey, crystalline quartz, varying from 8 in. to 30 in. wide, and lenticular masses of hard brecciated mica-schist. The form of the outcrop, as exposed in the steep face 50 ft. above the track, is shown in Fig. 25.

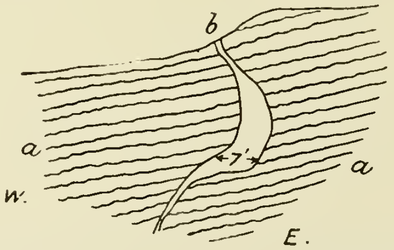


FIG. 25. CROSS-SECTION OF JUNCTION LODE NO. 2, NEAR MOUTH OF SKIPPER'S CREEK, SHOTOVER.
a. Mica-schist. *b*. Junction lode No. 2.

The outcrop of the lode can be traced northward for a distance of 10 chains.

The lode is enclosed between well-defined walls, and is found to vary in width from 8 in. to 7 ft. The structure of the lode-matter and its arrangement at the widest part of the lens, as shown in Fig. 25, is represented in Fig. 26.

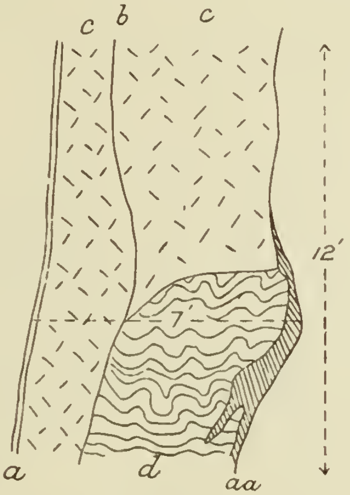


FIG. 26. ENLARGED SECTIONAL VIEW OF JUNCTION LODE NO. 2, SKIPPER'S POINT, SHOTOVER.
a. Vein of quartz, 1 in. to 4 in. *b.* Crack traversing lode. *c.* Brecciated mica-schist. *d.* Contorted mica-schist. *aa.* Foot-wall lens of quartz.

Samples of quartz selected from the hanging-wall and foot-wall veins showed gold at the rate of 1 dwt. 18 gr. and 2 dwt. 6 gr. per ton respectively.

The relationship of Junction No. 1 to Junction No. 2 lode is shown in the next figure.

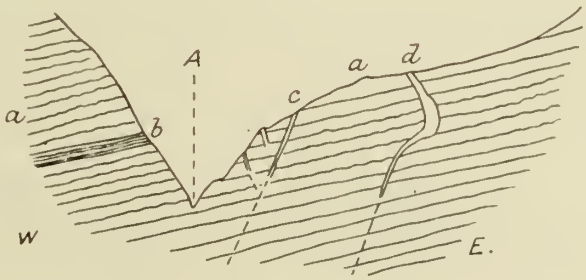


FIG. 27. SECTION SHOWING RELATIONSHIP OF JUNCTION LODES NOS. 1 AND 2.
a. Mica-schist. *b.* Chloritic mica-schist. *c.* Junction lode No. 1. *d.* Junction lode No. 2.
A. Skipper's Creek.

The Bridge Lode.—This lode crops out on the north bank of Skipper's Creek, about 50 yards above the foot-bridge on the Shotover bridle-track, and 100 yards above the mouth of Jennings Creek. It strikes 335° (true), and dips north-east at an angle of 45°. The enclosing rock is a crumbling silvery-grey mica-schist that strikes 17° (true), and dips westerly at an angle of 30°. The lode varies from 2 in. to 16 in. wide. It is well seen on the flat, shelving, schist ledge on the bank of the stream, where it forms a flat lens of quartz 20 ft. long, tapering from 2in. at the end to 16 in. at the widest part. (See Plate XXXVII.)

The lode-matter consists of hard, grey, crystalline quartz, containing a little pyrites. A sample of the ore selected from the outcrop of the lens showed by fire assay a return of 2 dwt. 18 gr. of gold per ton.

On the hanging-wall, and 25 ft. distant, there is a small parallel vein of quartz a few inches wide.

The plan and cross-section of this interesting lode are shown in Plate XXXVI, facing this page.

A sample of ore selected from the outcrop of the truncated lens exposed on the bank of the stream gave a return of 2 dwt. 18 gr. of gold per ton.

Lodes in Stevenson's Claim, Skipper's Point.—The sluicing-away of the terrace-gravels at Skipper's Point has uncovered several lodes on the platform that formed the channel of the Shotover in the glacial period. This old river- and glacier-channel lies 200 ft. above the present surface of the Shotover River, and is composed of a weak friable mica-schist intercalated with thin beds of chloritic mica-schist.

On the main floor there is exposed a broad platform of the bed-rock, some 2 acres in extent, and on this the upturned edges of the schist are beautifully exposed to view. By running the eye along any distinctive bed it is seen at once that the strike is not straight or uniform, but varies from 171° to 182°(true) at different points. The direction of the dip is westward, the mean angle of inclination being about 35°.

The apex of the ridge of rock lying between the two main glacial channels of the Shotover is traversed by a number of quartz veins, some of which are large well-defined bodies of stone, while others are irregular and small.

No. 1 lode crops out on the west side of the big platform, in an old tail-race. Its course is 178° (true), and it stands practically vertical at its northern end, but going southward it is seen to bend towards the south-east—that is, 160° (true). From the point where it changes its course it dips towards the north-east at an angle of 55°.

The lode-material consists of compact greyish-white quartz, varying from 2 in. to 2 ft. wide.

The plan of this lode, with its numerous hanging-wall branch veins, as seen on the floor of the bare rock platform, is shown in Fig. 28.

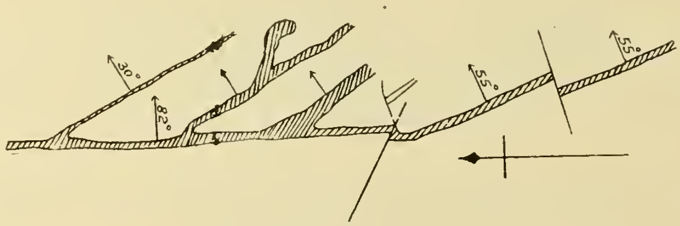
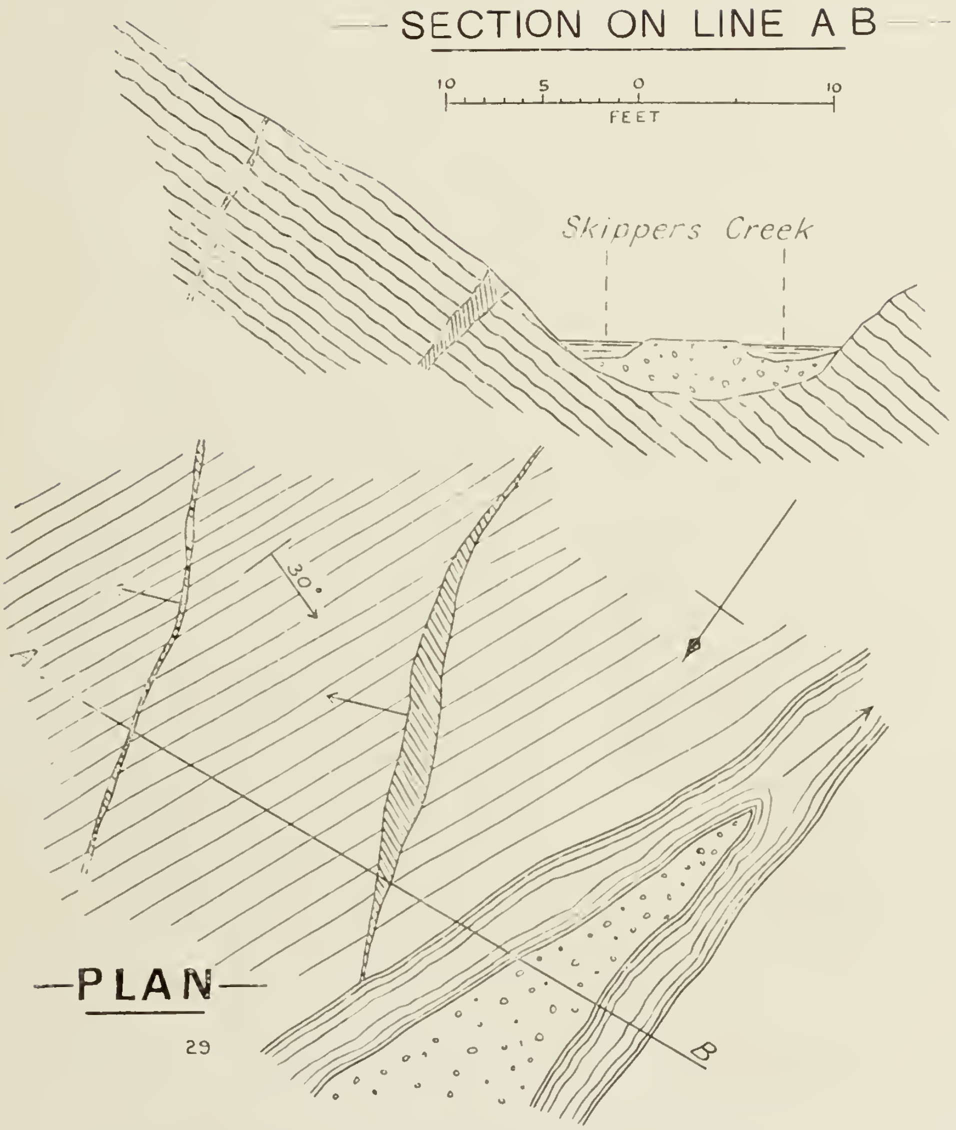


Fig. 28. Plan showing No. 1 Lode and its Branch Veins, Stevenson's Claim, Skipper's Point.

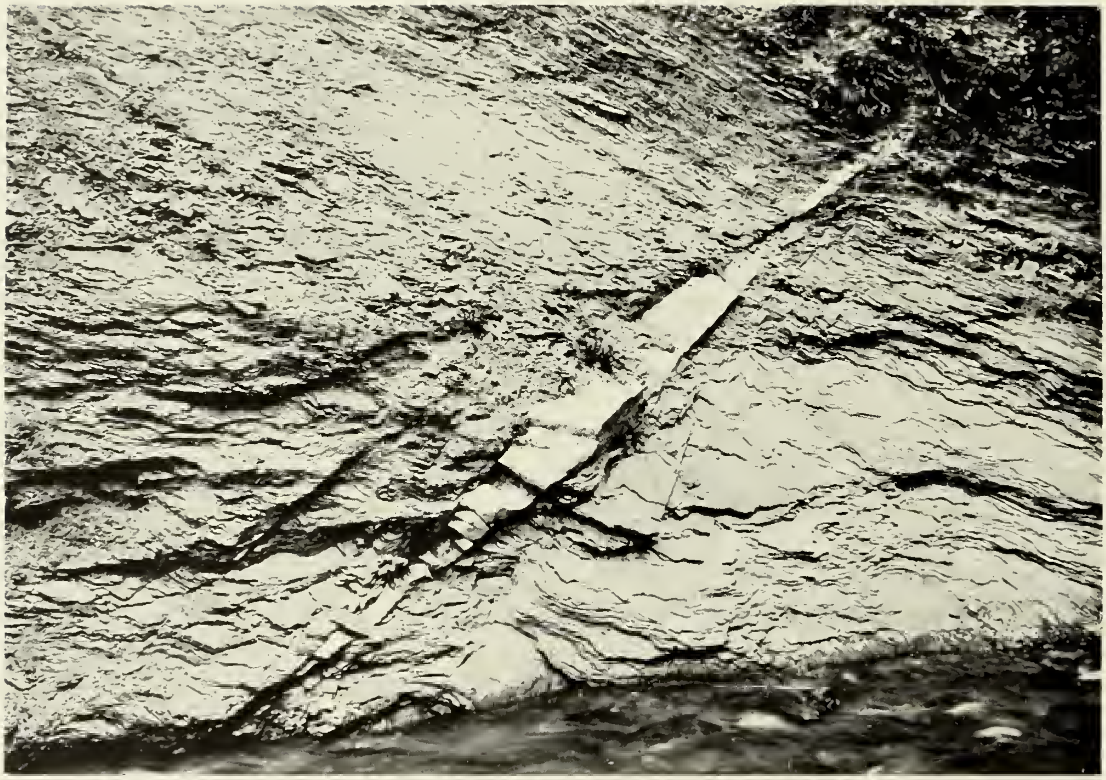
No. 2 lode is exposed on the floor and sides of the smaller and more easterly glacial channel of the Shotover. It consists of compact quartz, and is little better than a veinlet, varying from 1 in. to 4 in. wide. It strikes 148° (true), and dips north-east at an angle of 36°. On

PLATE XXXVI.



Plan and Cross-section of the Bridge Lode, Skipper's Creek.

PLATE XXXVII.



Lens of Quartz in Vein on Bank of Skipper's Creek, 50 Yards above Footbridge.

Photo James Park.]

the north wall of the channel it is seen to be slightly displaced by a small fault, as shown in the next figure :—

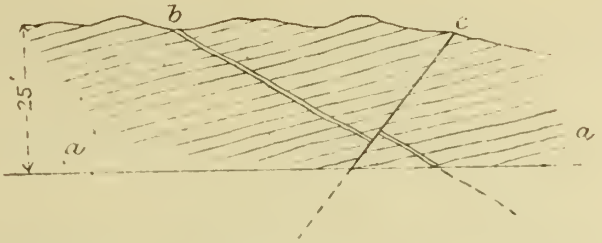


FIG. 29. CROSS-SECTION OF NO. 2 LODE, STEVENSON'S CLAIM, SKIPPER'S POINT.

a. Mica-schist. *b.* No. 2 lode. *c.* Fault.

No. 3 *lode* crops out near the lower end of the same rock-channel, which presents the appearance of a deep, well-excavated, railway rock-cutting. It is best exposed on the west side of an old tail-race. Its strike is 360° (true), and it dips east—that is, towards the Shotover River—at an angle of 35°.

The lode-matter varies from 4 in. to 4 ft. wide, and consists mainly of distinct bands of rusty-coloured quartz and broken schist, recemented into a solid mass.

The lode can be traced along the floor of the claim for a distance of 3 chains. It is a strong well-defined lode, and has probably some relation to one of the Junction lodes that crop out on the banks of Skipper's Creek near-by.

No. 4 *lode* crops out about 50 ft. west of No. 3. It strikes 170° (true), and stands vertical.

It varies from 4 ft. to 8 ft. wide, and consists of broken schist intersected with quartz veins that are rarely well defined. In some respects it resembles a zone of mineralised rock rather than a lode.

A sample of quartz selected at the outcrop was found by fire assay to contain 2 dwt. 6 gr. of gold to the ton.

No. 5 *lode* is a strong well-defined body of ore that unites with No. 4 lode at the north end of the trench. It consists of rusty-coloured quartz, varying from 6 in. to 4 ft. wide. Its strike is 192° (true), and for the first 55 ft. it stands nearly vertical, but thereafter it inclines to the eastward at an angle of 40°, sending off a branch vein that dips towards the east.

A sample of ore selected along the outcrop was found by fire assay to contain gold at the rate of 1 dwt. 18 gr. per ton.

The relationship of the last three lodes is represented in Fig. No. 30.

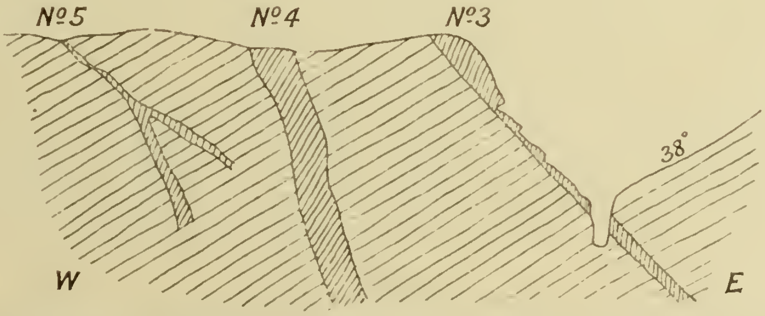


FIG. 30. CROSS-SECTION SHOWING RELATIONSHIP OF STEVENSON'S LODES NOS. 3, 4, AND 5, SKIPPER'S POINT, SHOTOVER.

Eureka Lode.—This lode crops out on the south side of Jennings Creek, about a mile from the junction of that creek with Skipper's Creek. It strikes 130° (true), and dips to the southward at an angle of 50°. The hanging-wall is well defined. The lode-matter, as seen at the outcrop, consists of crushed mica-schist and veins of quartz. Most of the quartz excavated from a surface trench on the outcrop shows shining slickensided surfaces, which tends to show that considerable movement has taken place on the walls since the formation of the lode.

Very little of the lode can be seen at the surface, on account of the overburden, but so far as could be ascertained the width between the walls varies from 2 ft. to 4 ft. Several attempts have been made to work this lode, but so far without success.

During the past twenty-five years a considerable amount of attention has been devoted to the prospecting of the Leviathan, Crystal, and Johnston lodes, situated on the ridge between Sawyer's Gully and Jennings Gully, the first two on the Sawyer's Creek fall, the latter on the Jennings Creek side, but so far without success.

Skipper's Gorge Lode.—This lode crops out in the bottom of Skipper's Gorge, about 26 chains below the mouth of Butcher's Creek. It varies from a clay parting to 4 ft. wide, and consists of crushed mica-schist, and quartz veins that commonly run parallel with the walls.

The lode strikes 320° (true), and dips south-west at angles varying from 62° to 75°. The enclosing rock is a soft mica-schist that strikes 355° (true), and dips west at an angle of 32°.

A sample of ore selected from the outcrop on the bank of the creek was found to contain gold at the rate of 3 dwt. 6 gr. to the ton.

Scheelite.

Up to the present time scheelite has not been found in the soft, silky, gold-bearing mica-schists of the Wakatipu area, but only in the harder semi-metamorphic schists of the upper or Kakanui Series. Thus, while traces are rarely found in the Arrow and Shotover rivers, pebbles, and even boulders, of the mineral have been often met with in the gravels of Moke Creek and those of the branch streams that traverse the upper schists.

There is reason to believe that quartz lodes carrying scheelite will be found between Moke Lake and Ben More, between Bob's Cove and Mount Crichton, and on the ranges around Lake Luna.

Copper.

Moke Creek Copper Lode.—This so-called copper lode, on examination, was found to be a narrow zone of mineralised schist which crops out on the banks of Moke Creek, about half a mile above the junction of Maconnachie's Creek, at an altitude of 1,560 ft. above sea-level. It varies from a few inches to 12 in. wide. The strike of the schist and enclosed copper-bearing zone is 355° (true), and the dip west at an angle of about 50°.

The copper-bearing ore consists of rusty-coloured quartz, in which occur irregular bunches and bands of copper and iron pyrites. It is enclosed on the foot-wall by a soft, bluish-grey, fissile mica-schist, much crushed and broken in the immediate vicinity of the copper zone, and on the hanging-wall by a greenish-grey chloritic schist, somewhat harder than the foot-wall rock. On the face of the creek-bank the enclosing schist is slightly stained with copper-carbonates for a width of 2 ft. or 3 ft.

The copper-bearing zone crosses Moke Creek at right angles to its course, and is well situated for examination. It has been prospected by two lodes, driven along the course of the mineralised belt, and by a number of shallow trenches and pits. No copper-ore could be seen in the face of the levels. Samples can be selected from the surface dumps giving from 5 per cent. to 20 per cent. of copper, according to the care devoted to the knapping and selection.

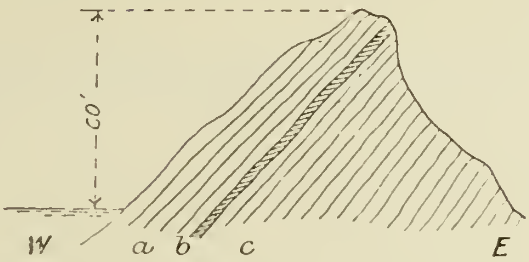


FIG. 31. CROSS-SECTION OF CUPRIFEROUS SCHISTS, MOKE CREEK; LOOKING NORTHWARD.
a and *c*. Mica-schist. *b*. Mineralised zone.

The copper-bearing band follows the foliation-plane of the schist, and is therefore what in Norway would be termed a *fahlband*. It is too small to be profitably worked at the present time.

Skipper's Point Copper Zone.—This is exposed in the floor of the terrace claims immediately below Skipper's Point. It is a mineralised zone of schist, consisting of intensely hard silicified chloritic mica-schist, in which there occur lenticular masses of blackish-brown ferro-manganese ore associated with epidote, garnet, calcite, rhodonite, copper, and specular iron. The copper occurs as incrustations of the green carbonate, and the specular iron as small and large grains disseminated throughout the garnet rock. The rhodonite commonly occurs in small irregular masses.

The ferro-manganese ore forms the bulk of the ore known to the alluvial miners as *black Maori.*

ANTIMONY.

Advance Peak Lode.—A quartz lode was discovered by a prospector near the head of Rodger's Gully, behind Advance Peak, at an altitude of 4,000 ft. above the sea, that yielded some samples of antimonite of good quality. The antimony-ore occurred as an isolated bunch at the outcrop. Antimony-ore is notoriously patchy, and there is every reason to believe that other bunches of ore will be found by driving along the course of the lode. But the great altitude, the scarcity of mine-timber, and the inaccessible position will at all times greatly militate against successful mining at this place.

Skipper's Point Antimony.—A considerable quantity of antimonite, as loose boulders, occurs among the alluvial wash in Stevenson's Claim. The ore is often quartzose, but much of it is high grade.

The source of this ore has not yet been found. It is unlikely that it can be far from Skipper's Point, as antimonite, being a soft ore, would not be able to withstand the pounding to which it would be subjected in the course of a long journey along the bed of a swift stream. The antimony-bearing lode will probably be found somewhere on the ridges lying between the Shotover and Skipper's Point.

ALLUVIAL MINING.

The gold-production of Otago from the year 1857 to the 31st December, 1906, amounted to 676,386 oz., valued at £26,519,060; and, of this great output, alluvial mining has produced somewhat over £25,000,000, or 98 per cent. of the whole. Of the total gold-production of the Dominion, amounting to a value of £69,501,488, Otago is responsible for no less than 35·5 per cent. For some years past Auckland has taken the lead in annual gold-production ; but, even if the present rate of production is maintained, it will take that province thirty years to reach the total yield of Otago.

It is satisfactory to note that alluvial mining in Otago still maintains a high place as a source of gold, and will doubtless continue to do so for many years to come.

In the Shotover and Arrow river-systems there are two main sources of alluvial gold—namely, (*a*) river-bed gravels and (*b*) terrace-gravels.

Terrace-gravels.—The most important of these deposits lies between Skipper's Point and Maori Point. It has been worked continuously for the past forty years.

The gravels forming this old gravel wash are composed of schistose material, in which occur a few black boulders of hornblende-lamprophyre, derived from dykes intruding the schists at the source of the Shotover, and occasional masses of the Tertiary fossiliferous conglomerate involved in the great Moonlight thrust-plane.

They vary from 150 ft. to 190 ft. thick, and rest in the old glacial channel of the Shotover, which lies about 200 ft. above the present level of the river. A reference to the special map of Skipper's Point will show the areas of gravel that have been sluiced away and those that still remain.

The best of the gold is found at or near the schist-bottom, and in the layers of coarse wash that in places occur a few feet or a few yards above the bottom.

The pay-wash occurs partly in short leads and partly in irregular patches. The richest patches have been found in places immediately below the point where the lateral streams that descend from the Richardson Mountains enter the Shotover Valley. Among typical examples of historic fame occurring in such situations are those at the junctions of Skipper's, Sawyer's, Londonderry, Pleasant, and Stony creeks.

In the pioneer days the gold-wash was driven out by underground mining, but in the past two decades large areas of the gravels have been bodily removed by hydraulic sluicing. There still remains a considerable area of gold-bearing wash that will continue to furnish gold for many years to come.

The distribution of the gold-wash shows that, while a portion of the gold has been brought down by the Shotover, a part, and by far the greater part, has been contributed by the lateral creeks. Of these contributory streams Skipper's Creek is the most important. This stream, with its numerous branches, follows and deeply dissects the belt of mica-schist that contains the greatest number of productive gold-bearing lodes in the district. On the other hand, Stony Creek has been less productive, which is doubtless due to the circumstance that only in the lower few miles of its course does it pass through the gold-bearing zone of schist.

Isolated patches of high terrace-gravels occur overlooking Butcher's Gully. The causes that have led to the enrichment of the wash at the mouth of Skipper's Creek must have operated in the enrichment of these patches, although doubtless in a somewhat less degree.

Monk's Terrace, nearly opposite Sandhills Creek, has proved a profitable source of alluvial gold for some years. The gold was probably brought there by the small lateral stream immediately above the claim. A search of the watershed of this stream would no doubt reveal a gold-bearing lode somewhere in the neighbourhood.

A high terrace of gold-bearing gravel wash lies along the bottom of Moonlight Gully, its greatest extent lying between the mouth of Moke Creek and Dead Horse Gully. It occupies the floor of the Moonlight glacial valley. Enrichment of the wash has taken place at the mouth of Moke Creek in the ground worked by the Moonlight Hydraulic Sluicing

Company, and at the mouth of Dead Horse Gully; but the enrichment was not comparable with that at Skipper's Point, as Moke Creek and Dead Horse Gully for the greater part of their course run outside the gold-bearing zone of mica-schist, which is the silvery-grey crumbling mica-schist so well developed at Macetown and Skipper's Creek.

The high glacial terrace on which Macetown stands contained some rich runs of gold-wash, that for the most part owed their origin to the gold carried down by the Goldburn, the gold having been derived from the denudation of the lodes of the Tipperary-Premier system of reefs.

Above Macetown the Arrow River runs for the greater part of its course in the unproductive zone of country rock underlying the gold-bearing zone, only some of the western tributaries that rise on the slopes of Advance Peak cutting back far enough to the westward to reach the lower edge of the productive mica-schist.

A portion of the fluvio-glacial drift at the Arrow end of the Crown Terrace has yielded rich returns from a short run of gold-wash, the source of which lies in the area between Mount Beetham and Bracken's Gully.

An old fluvio-glacial channel runs along the foot of Coronet Range, from Miller's Flat towards Arthur's Point. It probably contains a run of gold-wash, but whether the wash is payable and of some extent can only be determined by boreholes or prospecting-shafts.

River- and Stream-bed Wash.—The Arrow and Shotover rivers for countless ages before the advent of man acted as natural sludge-channels, in which the gold, liberated from the lodes in the adjacent country by fluviatile dissection and glacial erosion throughout a geological period, became concentrated in pockets and leads, as it does in the tail-race of the modern miner.

The pioneer miners began operations by cleaning up the beds of the rivers and streams. The pay-wash was generally shallow, and often fabulously rich. The country swarmed with thousands of enterprising men, and before the close of the seventies practically all the shallow ground was exhausted. Small areas of deep ground, however, existed in the Arrow Gorge and in the Shotover at Arthur's Point, and these yielded rich returns for many years. Among the most successful of the dredging-claims taken up in the Shotover was the Sew Hoy Claim, on the Big Beach, near Arthur's Point, on which a dredge was erected by a Chinese merchant of that name in 1889.

There is a well-founded belief among the local miners that a large amount of gold still lies in the bed of the Shotover. The ground is deep, and the mechanical difficulty of recovering the gold is very great. With each successive year the cover of wash is becoming deeper and deeper, through the large amount of gravel sluiced into the river at and near Skipper's Point. To turn the river is impracticable, and for the present the gold must lie undisturbed.

Lake Hayes Limestone.

The high terrace at the south end of Lake Hayes consists of finely bedded silts, or rock-flour, occurring in distinct drab- and grey-coloured horizontal laminæ. On examination the grey-coloured layers are found to consist of soft incoherent limestone, occurring in excessively fine particles.

Passing eastward from the outlet towards the corner of the lake near Morven Hill, and westward toward Messrs. Reid and McDowell's farm, the drab-coloured layers gradually thin out in the middle horizon, being replaced by the limestone layers, which widen out at the south-east and south-west corners of the lake to deposits of considerable extent and great purity.

The section of the terrace exposed at the south-east corner is shown in Fig. 32 below, and in Plate XXXVIII.

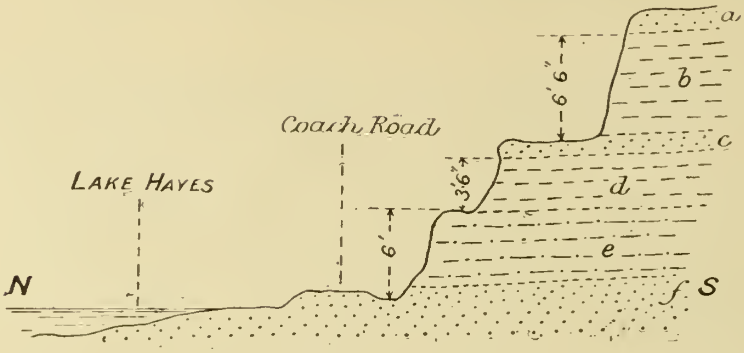


Fig. 32. Section showing Deposit of Limestone at South-east Corner of Lake Hayes.

a. Surface soil. *b.* Limestone. *c.* Drab-coloured silt, from 2 ft. to 3 ft. thick. *d.* Limestones. *e.* Impure limestone. *f.* Drab-coloured silt.

The section exposed in Messrs. Reid and McDowell's limestone-deposit at the south-west angle of the lake is shown in the next figure :—

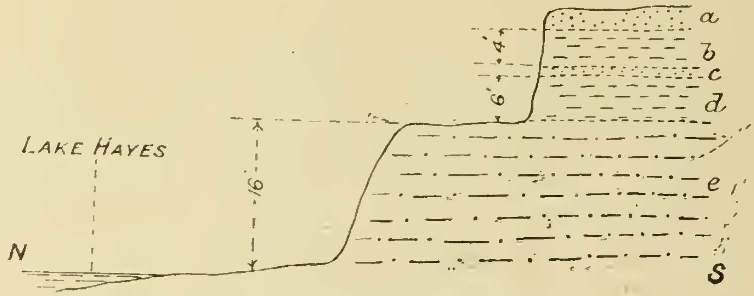


Fig. 33. Section showing Face of Reid and McDowell's Limestone-deposit at South-west Angle of Lake Hayes.

a. Surface soil, 2 ft. 3 in. thick. *b.* Limestone, 4 ft. thick. *c.* Drab-coloured silt, 6 in. to 12 in. thick. *d.* Limestone, 6 ft. thick. *e.* Impure limestone, drab-coloured.

This limestone is a fresh-water deposit that was formed in still water. It was no doubt precipitated from the waters of the lake by the action of mosses and fresh-water algæ.

The material is excessively fine in texture, and so soft as to be easily excavated with a spade without exerting much force. Its purity and pulverulent form render it of great economic value for agricultural purposes, both for dressing the land and in the manufacture of manures. Already several hundreds of tons of it have been bagged and forwarded to Southland.

The extent of the deposits at the places described above is not known, and can only be determined by boring or sinking shafts on the terrace. If the thickness

PLATE XXXVIII.

Quarry of Calcareous Ooze (Limestone), South-east End of Lake Hayes.

Photo James Park.]

as exposed in the present working-faces be maintained, it is estimated that each acre should contain some 12,000 or 15,000 tons of limestone of marketable quality, and 10,000 tons of impure limestone suitable for top-dressing agricultural and pastoral lands that are deficient in lime.

The results of the analyses of samples of the pure and impure limestone made by Dr. J. S. Maclaurin, D.Sc., F.C.S., Dominion Analyst, are given below in tabulated form :—

	1.	2.	3.	4.	5.
Silica	7·15	41·90	10·78	6·30	10·54
Alumina	3·24	18·50	5·12	2·61	4·28
Ferric oxide	2·00	7·68	2·40	1·76	2·12
Manganous oxide	0·07	0·25	0·05	0·05	0·12
Lime	47·70	12·52	44·25	48·44	45·30
Magnesia	0·20	2·57	0·40	0·25	0·30
Carbonic anhydride	36·90	8·32	34·43	37·85	34·80
Moisture and organic matter ..	1·77	3·72	1·03	1·57	1·61
Undetermined	0·97	4·54	1·54	1·17	0·93
	100·00	100·00	100·00	100·00	100·00
Equivalent to calcium-carbonate	83·86	18·91	79·16	86·02	79·15

1. Top layer, south-east side of Reid and McDowell's quarry.
2. Grey band (middle layer).
3. Lower band, 6 ft.
4. Impure limestone at base.
5. Average sample of whole face.

Bob's Cove Limestone.

The middle member of the Tertiary Series at this place consists of some 75 ft. of limestone, of which there is a band of great purity and extent 50 ft. thick. This bed of limestone can be traced along the surface for a distance of 40 chains. It rises from the level of the lake to a height of over 1,600 ft. above the sea, and is exposed in such a manner as to offer great facilities for easy and economical working (see Fig. 17). The quantity that could be excavated above water-level, without the removal of much overburden, amounts to over 2,500,000 tons.

The limestone is close in texture, semi-crystalline in structure, and very hard. The colour is a pale-yellowish grey to drab. A sample analysed by Mr. G. M. Thomson, F.L.S., gave the following results :—

Calcium-carbonate	92·42
Alumina and iron-oxide	3·60
Silica and insoluble matter	4·03
Total	100·05

This limestone is suitable for burning for lime for mortar and agricultural purposes, and for the manufacture of cement. It possesses all the characteristics of a first-class building-stone, including strength, durability, and good colour, and, having a fine texture, it is easily worked, and takes a fine polish.

Bob's Cove Marl.

This forms one of the lowest members of the Tertiary Series. It is several hundreds of feet thick, and is simply a hardened sea-mud, having the following composition :—

Analysis by Mr. G. M. Thomson, F.L.S.

Calcium-carbonate ..	34·52
Calcium-oxide (otherwise combined) ..	2·39
Alumina and oxide of iron ..	6·50
Magnesia ..	0·72
Silica and insoluble matter ..	51·60
Alkalis and loss ..	2·51
Moisture ..	1·76
Total ..	100·00

The marl and limestone are admirably adapted for the manufacture of cement. Both occur close to deep water, both exist in immense quantity, and there is a sufficient supply of water in the Twelve-mile Creek near-by to provide all the motive power required in the manufacture. The only disability that exists is the absence of a known coal-deposit in the vicinity.

Given a supply of cheap coal, there is no place in New Zealand where a high-class cement could be manufactured to better advantage, barring the freight-charges on the manufactured article to the market. But, despite these, a flourishing industry might easily be established if cheap fuel could be procured.

Coal.

The only place in the Wakatipu district at which there is a likelihood of finding coal is at Bob's Cove, where there is a patch of the Tertiary brown-coal measures of Otago and Southland.

Some years ago a borehole was put down close to the edge of the lake, at a place a few chains east of the limestone outcrop. The borehole was vertical, and its site was not selected with much care or regard for the disposition of the strata.

At the borehole the dip of the beds is about 55°, and, considering the great thickness of the marly clays underlying the sandstone in which the hole began, it is obvious that the depth to be bored to reach the coal-horizon, which in its turn underlies the marly clays, would probably not be less than 800 ft.

The most promising site for boring is situated at the back of the limestone ridge, in the small swampy bight near the foot of the escarpment that faces the flat along which the road passes to Bob's Cove. On account of the high angle at which the beds are inclined, it would be advisable to put the borehole down at an angle of 30° or 40° from the horizon, in a northerly direction. If coal exists at all in the measures at Bob's Cove, it will be under the flat spoken of above.

A thin streak of coal about 2 in. thick occurs in the wedge of Tertiaries involved in the schist in Seffer's Creek, which falls into Moke Creek a mile or less below the outlet of Moke Lake ; but it is of no value, and gives promise of nothing better.

The discovery of coal at Bob's Cove would be of great importance to Queenstown and Wakatipu district, and is a matter that should not be lost sight of. The presence of the coal-measures is no guarantee that workable coal will be found, but the prospects are not unfavourable.

Building-stones.

Altered Greywacke.—The semi-metamorphic schists and altered greywacke found at Lake Dispute, and forming Walter and Cecil mountains, are strong compact building-stones of good colour, that could be easily hewn into market sizes and shapes.

A good quarry could be opened at the upper end of Lake Dispute, or on the shores of Lake Wakatipu opposite Queenstown.

The Lake Dispute stone is of superior quality, and could be obtained in large blocks at a comparatively small cost. The distance from the quarry to the shore of Lake Wakatipu would be about two miles of down grade, on which a self-acting aerial tramway would work with ease.

Bob's Cove Sandstone.—This is a yellowish-brown sandstone of even grain, and a hardness somewhat above that of English freestones. It is a superior building-stone, that is easy to quarry and dress by hand-labour.

A quarry could be opened at a point a few chains from the shore of the lake. If this stone could be placed on the market at a reasonable price, it would be certain to command a ready sale.

Bob's Cove Limestone.—This is a stone of superior quality for building purposes. It is dense, homogeneous, strong, of good colour, and easily worked. A quarry could be opened quite close to the shore of the lake.

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By Authority: John Mackay, Government Printer, Wellington.—1908.

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